STUDY ON APPLICATIONS OF ADVANCED MANUFACTURING TECHNOLOGIES IN AUTOMOTIVE SECTOR

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CANDIDATE’S DECLARATION

I, hereby certify that the thesis titled “Study on Applications of Advanced Manufacturing Technologies in Automotive Sector”, submitted in fulfilment of the requirements for the award of the degree of **Doctor of Philosophy** is an authentic record of my research work carried out under the guidance of **Dr. Suresh Kumar Garg** and **Dr. Rajesh Kumar Singh**. The matter presented in this thesis has not been submitted elsewhere in part or entirely to any other university for award of any degree.

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SUPERVISORS' CERTIFICATE

This is to certify that the thesis titled, "Study on Applications of Advanced Manufacturing Technologies in Automotive Sector", submitted in fulfilment of the requirements for the award of the degree of **Doctor of Philosophy** is an original research work carried out under our supervision. The matter presented in this thesis has not been submitted elsewhere in part or fully to any University or Institute for the award of any degree, to the best of our knowledge.

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ABSTRACT

The manufacturing industries are undergoing phenomenal changes all across the globe. Competitive pressures and market dynamics urged the manufacturing processes to enhance their productivity and performance. Moreover, crucial need to reduce the cost and maintaining the high quality standards is raised by customers. The role of automotive sector is highly significant in growth of the emerging economy like India. Industrial Managers, Policy makers, Practitioners needs to be on forefront to adopt these technologies. However, implementation of AMTs is quite cumbersome and require sincere efforts from all the stakeholders.

Though all the sectors of economy are facing above mentioned scenario. However automotive sector has more challenges due to its fast growth especially in emerging economy like India. In the past three decades' Indian automotive sector has grown many fold in terms of customers, volume, models and exports. The sector has adopted several Advanced manufacturing technologies like Industry Internet of things, Industry 4.0, and Artificial Intelligence etc. Despite many folds growth there is further need to adopt new technologies.

Therefore, the purpose of present study is to examine the implementation of AMTs in automotive sector. This study is organized into eight chapters. First chapter deals with the introduction of AMTs. Second chapter deals with the literature review. Third chapter deals with the research methodology. Fourth chapter deals with the justification of Advanced manufacturing technologies using the methodology of Analytic Hierarchy Process (AHP). Fifth chapter with the Prioritization and evaluation of barriers intensity index for advanced manufacturing technologies implementation using AHP and Graph Theory and Matrix Approach (GTMA). Sixth chapter deals with the Prioritizing of Critical Success Factors (CSFs) for implementation of Advanced Manufacturing Technologies using Fuzzy Topsis Approach. Seventh chapter deals with the real case studies which helps to validate the findings with the

help of SAP-LAP Approach. Eighth chapter deals with the discussions and the last chapter deals with the conclusion and implications.

Major research findings reveal that adopting AMTs results in reduced wastage and optimum utilization of resources. Moreover, it helps to enhance operational performance and organizational excellence. Barriers to adopting AMTs were assessed using the GTMA approach. The barrier intensity index was evaluated. It was analyzed that finance and economic barriers had the highest intensity of barriers. The second highest barrier category was operational and strategic barriers. Moreover, the topmost CSFs were found to be strategic planning for implementing AMTs and top management commitment. Top management must conduct training and educational programs so employees feel comfortable using AMTs. Furthermore, the case study was analyzed using the SAP-LAP approach to analyze major contributing factors toward AMTs implementation.

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ABBREVIATIONS

ABAS	Activity Based Accounting Systems
AGV	Automated Guided Vehicle
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AIS	Automated Inspection System
AM	Additive Manufacturing
AMHS	Automated Material Handling Systems
AMTs	Advanced Manufacturing Technologies
ANP	Analytic Network Process
AR	Augmented Reality
AS/RS	Automated Storage and Retrieval System
BDA	Big Data Analytics
CAD	Computer Aided Design
CAGR	Compound Annual Growth Rate
CAE	Computer Aided Engineering
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CE	Circular Economy
CPPL	Cleaner Production Promotion Law
CIM	Computer Integrated Manufacturing
CNC	Computer Numerical Control
CPS	Cyber-Physical System
CSF	Critical Success Factor
DEA	Data Envelopment Analysis
DEMATEL	Decision Making Trial and Evaluation Laboratory
DNC	Direct Numerical Control
ERP	Enterprise Resource Planning
FEB	Financial and Economic barriers
FMS	Flexible Manufacturing System
GTA	Graph Theoretic Approach
HB	Human Barriers
HCI	Human-Computer Interaction

HMI	Human-Machine Interaction
H-CPS	Human-Cyber Physical System
IBEF	India Brand Equity Foundation
IoT	Internet of Things
IIoT	Industrial Internet of Things
ICT	Information and Communication Technologies
IEGR	Intelligent Exhaust Gas Recirculation
JIT	Just in Time
ML	Machine Learning
MRP	Material Requirement Planning
MRP-II	Manufacturing Resource Planning
MSME	Micro, Small and Medium Enterprises
NPD	New Product Development
OSB	Operational and strategic barriers
PLC	Programable Logic Controller
PPE	Personal Protective Equipment
SCADA	Supervisory Control and Data Acquisition
SCR	Selective Catalytic Reduction
SDG	Sustainable Development Goals
SME	Small and Medium Enterprises
SPC	Statistical Process Control
TOPSIS	Technique for Order of Preference by Similarity to Ideal Situation
TIB	Technical Information barriers
TOPSIS	Technique of Order of Preference by Similarity to Ideal Solution
TPS	Toyota Production System
TQM	Total Quality Management
TFN	Triangular Fuzzy Number
VR	Virtual Reality
WASPAS	Weighted Aggregated Sum Product Assessment
WHO	World Health Organization

Chapter-1: Introduction

1.1 Background

Recent technological innovations are reshaping the future of manufacturing organisations. These organisations are going through cutthroat competition. The demand for high quality products at lower prices requires the organisations to rethink their manufacturing system. Organizations relying earlier on manual processes are transforming into automation so as to reduce repetitive work and increase accuracy. The introduction of technologies in the automotive sector is transforming traditional processes and bringing new opportunities. As per pwc report, India is aspiring to have 25% GDP from manufacturing sector by year 2025 (CII-PwC, 2022). Also, PIB (2022) report mentioned that the worth of automotive industry in India have a value greater than USD 100 billion which adds 8% of overall export and approximately 2.3 % of nation's GDP. Also, it is going to become third largest across the globe by year 2025.

Digital transformations are underpinning the manufacturing landscape, connecting cyber and physical world. Industry 4.0 bolster high level of connectivity among equipment and helps in optimum utilization of resources (Storenelli et al., 2021). Even use of digital technologies are mentioned in supply chain resilience (Balakrishnan et al., 2021). The findings found by Westermann et al., (2013) reveal that digitalization technologies result in 9% more revenue generation and profitability enhancement by 26% approximately. The manufacturing sector is the great hub which is contributing significantly to the GDP of the country. In the last few decades, the emergence of automation has drastically changed the way of doing work. Mass personalization, increased flexibility and customer satisfaction is the central focus for using AMTs (Sony and Naik, 2020). AMTs have a crucial role in enhancing supply chain resilience. The key technologies used are Blockchain, IoT, robotics, advance simulations and data analytics, cloud computing, autonomous systems, machine learning and so on. However, the flawless operations of these technologies are a challenge at present (Mourtzis et al., 2022). Through this, organizations have a competitive edge and are performing well in the global landscape. In recent years, the emergence of these technological innovations and Advanced Manufacturing Technologies (AMTs) helped the organizations to become more agile and responsive. Also, AMTs implementation helps to enhance manufacturing flexibility, reduce cost, lead, product development and delivery time (Singh and Gurtu, 2021). Further, it is regarded as backbone to revolutionize all functional areas of organizations (Hu et al., 2022). Also, the demand of mass personalization from the customers compels the industries to adopt AMTs (Mourtiz et al., 2022). AMTs act as an umbrella to cover various computer-based technological innovations to enhance organization’s competitiveness (Ghobakhloo and Azar, 2018). AMTs have strong linkage with eco-sustainability and Industrial Internet of Things (IIoT) (Hu et al., 2022). Furthermore, AMTs is considered as potential facilitator to lean and agile manufacturing (Ghobakhloo and Azar, 2018). However, scholarly literature reveals that AMTs implementation is subjected to various challenges. The roadblocks can be bifurcated into different categories including economic, personnel, regulatory, technological and strategic (Storenelli et al., 2021). In the similar context, various research studies assessed the association between AMTs implementation, organizations vision and strategy (Da Costa and Lima, 2009).

AMTs have high potential to enhance innovative capabilities of the organization. Innovation found to mediate the relationship between AMTs implementation and organizational performance (Altuntas et al., 2018).

1.2 Types of Advanced Manufacturing Technologies

Globalization has a momentous impact on society and economy (Zeba et al., 2021). Due to high competition, it is highly essential for the organisations to upgrade and reorganize (Liu et al., 2022). The digital wave is blowing across the globe, Germany initiated the concept of Industry 4.0, Japan introduced Society 5.0, and India presented SAMARTH Udyog Bharat 4.0.

Advanced manufacturing technology is a crucial component of Industry 4.0, the fourth industrial revolution that integrates cyber-physical systems, IoT, and data analytics. Industry 4.0 aims to establish smart factories that are more efficient, produce higher quality products, have lower costs, and are more sustainable. Advanced manufacturing technology plays a key role in achieving this transformation. Advance manufacturing technologies automate manufacturing processes, provide real-time monitoring and control, and optimize production schedules. The most significant benefit of advanced manufacturing technology is its ability to create highly flexible and adaptable smart factories (Longo et al., 2017). Manufacturers can quickly respond to changing market demands and customer requirements, which leads to quick time-to-market, higher quality products, and reduced prices (Yang et al., 2018).

Moreover, advanced manufacturing technology creates a more sustainable manufacturing environment by optimizing energy usage, reducing waste, and minimizing the environmental impact of manufacturing processes (Huerta-Torruco et al., 2022). This helps manufacturers comply with environmental regulations and improve their sustainability credentials. In conclusion, advanced manufacturing technology is an essential component of Industry 4.0, enabling manufacturers to build smart factories that are flexible, adaptable, and sustainable. As the manufacturing industry continues to evolve, advanced manufacturing technology will play an increasingly significant role in promoting innovation, improving efficiency, and helping manufacturers stay competitive in a rapidly changing market (Li et al., 2022).

Artificial Intelligence (AI): Artificial Intelligence plays crucial role in advance manufacturing technology. In the data-driven today's scenario, AI driven systems are extremely crucial. AI are also being used in quality control which otherwise are very hectic and subject to errors.

Organization gather data from various equipment operating on shop-floor, this unstructured data needs to be converted in to structured data so that effective decision can be taken (Zeba et al., 2021). AI helps to take smart decisions based on past data and real-time analysis of current data. Even AI based systems are used for predicting the balance life of machines and its usability (Yang et al., 2018).

Virtual Reality (VR): There are variety of applications of VR in manufacturing including cyber-physical system (Yun and Jun, 2022), human-robot workplace analysis (Malik et al., 2020), Simulation (Huerta-Torruco et al., 2022), maintenance (Burova et al., 2022). Also, VR applications helps to analyze the faults at the preliminary stage during product design process i.e. before proceeding it for manufacturing thereby saves material, time and cost.

Additive Manufacturing (AM): It is also called 3-D printing, which focuses on layer by layer addition of material to create 2D shapes which then forms 3-D shapes. AM is characterized by better product design, increased accuracy and reliability. It has resulted in to cost reduction, enhanced accuracy and efficiency in manufacturing processes.

Internet of Things (IoT): Industry 4.0 environments facilitates the remote monitoring and execution of manufacturing processes through IoT networks. The data from machineries, equipped with smart sensors, sent over wireless networks using IoT devices. IoT also helps in fault detection, maintenance schedules and predictive maintenance.

Cyber-Physical System (CPS): It make use of various advancements of various branches of engineering i.e. computer science, electronics, IT and mechanical to operate and control production activities. Various physical equipment is connected over wireless networks and communication devices to share data and information distantly. The future manufacturing seems to be characterized by collaboration of various stakeholders to provide high quality products and services (Monostori et al., 2016). The authors further explained that both virtual and physical world environment developed in a parallel fashion. Some of the CPS examples include cobots, drones and sustainable and smart cities (Broo, 2022). However, few concerns raised for using CPS are security issues, safety, interoperability, reliability, and economics (Wang et al., 2015)

Augmented Reality (AR): AR systems are gaining attentions as it helps to add on required digital information on the real and physical world, thus enable to do task more precisely (Nee et al., 2012). There are numerous applications of AR in manufacturing including maintenance (Ariansyah, 2022), training, production, marketing. The authors stated that the research in context of AR-user interaction is very limited which may lead to mishaps and occupational hazards.

Digital Twin: Smart manufacturing have its roots based upon digitalization (Shao and Helu, 2020). The authors also discussed that this concept is having widespread popularity immensely that in USA, two third of the industries are projected to have at least one digital twin facility by 2022. As the name implies, digital twin is digital copy of physical entity which helps the manufacturer in real-time gathering of data, analysis, control and decision-making process (Li et al., 2022).

Blockchain: New technologies including Blockchain have transformed the industrial landscape. It is also highly emerging technique accepted worldwide in variety of applications. Centralized method for sharing information are susceptible to errors, also trust issues are encountered with the third party. To counter these issues, Blockchain is emerged to have decentralized peer to peer network with immense flexibility, security and high scalability. It also helps in increased transparency and traceability across the supply chain (Longo et al., 2019). As highlighted in scholarly literature, trust and sharing of information are extremely important for supply chain resilience and performance.

1.3 Research Gaps and objectives

The automotive sector is undergoing transformational digital transformations (IBEF, 2022). Reduced product life cycle and intense competition are compelling industries to adopt AMTs and increase flexibility, agility and user's satisfaction (Suleiman et al., 2021). The authors further concluded that AMTs are positively associated with Just in Time practices. AMTs have resulted in a lot of creativity and innovation, helping industries survive in a competitive marketplace (Stornelli et al., 2021). Analogous findings were stated by Mathew et al. (2020), who analysed the selection of AMTs using spherical-based fuzzy sets.

Most of the Indian Manufacturing industries are small and medium scale. As per Forbes (2023) reports, 96% of the companies are small scale industries. Till year 2022, total number of MSME registered are 1.28 crores. Most of the Indian industries face the challenge of shortage of funds, lack of skilled manpower, deficiency of adequate resources, absence of top management assurance (Kamble et al., 2019). Similar findings were illustrated by Jena & Patel (2022) and Majumdar et al. (2021). Also, India industries face issue of employee resistance to change and lack of adequate infrastructure, which impede them towards AMTs adoption (Vinod & Shimay, 2023).

Moreover, Ford and Despeisse (2016) discussed that adopting AMTs results in sustainable business models. Also, Stornelli et al. (2021) categorized the AMTs roadblocks into distinct categories, including Economic, Organizational, Human Resources, Technology and Regulatory. Ghani et al. (2002) discussed that equally important is to plan to change. Top management and AMTs experts play significant roles in tackling these issues. Looking at the last few decades, technology has completely revamped society (D'Aveni, 2015).

Moreover, the market has excessively become competitive, and the nitty-gritty of industries lies in adopting AMTs and becoming updated in the market landscape (Kamble et al., 2018).

Agostini and Nosella (2020) highlighted similar aspects. The authors presented that AMTs play a momentous contribution in high responsiveness, effective and efficient control of manufacturing processes. Top management commitment and support are essential factors in AMTs adoption (Birasnav et al., 2019). Investing in AMTs is a boon for nations, resulting in tremendous growth (Zheng et al., 2021). Adopting AMTs is quite cumbersome and complex; therefore, it is more complex than it seems (Oettmeier & Hofmann, 2017). Similar findings were reported by Kroll et al. (2016) and Stentoft et al. (2019). Therefore, industries must adopt AMTs to have digitalization across the value chain.

Moreover, Stornelli et al. (2021) mentioned that most of the scholarly literature in the context of AMTs adoption discussed technology and strategy as key enablers of AMTs adoption. Although many studies have been done in the context of AMTs adoption patterns in developed economies, limited studies are available in developing economies, specifically in the Indian automotive sector. Adopting AMTs in the automotive sector can result in exponential growth, increased market shares and profitability. The various gaps were identified after reviewing the scholarly literature, including Scopus, Science Direct, EBSCO, and Web of Science. The barriers to AMTs adoption are yet to be examined and assessed in the prevailing business environment in context of India. The barriers intensity index is also not evaluated in context of India. Moreover, the critical success factors for AMTs adoption are not mapped with performance factors and are prioritized in the context of the India emerging business environment. In-depth case analysis using robust case study models can be conducted to examine for AMTs adoption. Therefore, there is need to study different issues observed and study is required to justify AMTs application in automotive sector. Analysing the challenges and critical success factors for successful implementation of AMTs.

Therefore, to bridge the gap following research objectives are framed:

RO1: To justify the use of AMTs in Indian automotive sector?

RO2: To analyze key barriers for adopting AMTs in developing economy context like India.

RO3: To compute index value to evaluate barriers intensity.

RO4: To assess critical success factors for implementing AMTs in automotive sector for performance improvement.

RO4: To analyze real case study to validate the findings.

1.4 Research Motivation

Several research motivations drive the AMTs adoption in the automobile industry in India. With time, market competition is increasing exponentially (Agostini et al., 2020). As a result, the profit margin is decreasing. Therefore, operational processes must be more effective and efficient to meet customers' demands on time. In the present times, Digital technologies are proven to have fabulous results in every industry sector, including manufacturing (Xian et al., 2023), construction (Kaya et al., 2023), healthcare, and automobiles (Akthar et al., 2023). Therefore, it is for the Indian industry to revamp its operational processes to make them more efficient and effective. The Indian automobile industry operates in a highly competitive market, and implementing AMTs can improve product quality, reduce costs, and increase operational efficiency. Research in this area can focus on identifying technologies that provide a competitive advantage. Moreover, motivation is the desire to increase productivity. AMTs such as robotics, automation, and artificial intelligence have the potential to boost productivity in automobile manufacturing significantly (Mathew et al., 2020). Research can explore how these technologies can optimize production processes, minimize downtime, and improve overall efficiency, leading to higher output and shorter time to market.

Furthermore, Quality enhancement is also a crucial factor. Maintaining high product quality is essential for automobile manufacturers, and advanced manufacturing technologies offer precise control over manufacturing processes (Stornelli et al., 2021). As adopting AMTs is a complex process, research was needed to investigate how challenges can be overcome in the Indian automotive industry, thereby improving product reliability and safety. The optimization of supply chains is another research motivation. The Indian automobile industry relies on complex supply chains, and advanced manufacturing technologies like data analytics and supply chain management systems can optimize logistics, inventory management, and production planning (Suleiman et al., 2021). Research is required to investigate the effective implementation of these technologies to streamline the supply chain and reduce costs. Sustainable manufacturing is also a growing concern, and AMTs can help the Indian automobile industry transition towards environmentally friendly practices. Another pivotal concern is Skill development for the successful adoption of AMTs. Research can focus on identifying the critical success factors to understand the pivotal variables for successful AMTs adoption.

1.5 Originality/Significance of Research

It is highly significant to understand and assess the importance of AMTs. To assess these aspects, initial study comprised of analyzing the adoption of AMTs over traditional methods was examined using fuzzy-AHP approach. Moreover, to the best of our knowledge, a research study dealing with mathematical modelling of the barriers to AMTs adoption is not available in the current literature. Therefore, the presented study used Graph Theoretic Approach (GTMA) to assess the industry readiness toward AMTs adoption. The results can be used to compare the industry performance with the maximum and minimum values. Therefore, presented study provided a platform to industries to check their industry readiness towards AMTs adoption. Thus, top management can take necessary actions accordingly to overcome the issues. Furthermore, mapping AMTs performance indicators with CSFs gives clarity to the managers, researchers and practitioners about the crucial parameters which must be taken into account well in advance for effective AMTs adoption. Moreover, an in-depth case study analysis dealing with AMTs adoption to meet sustainable development goals provides input to the industries to revamp themselves and become more agile and flexible.

1.6 Organization of Thesis

The whole thesis is organized into eight chapters. Brief description of listed chapters is discussed as follows:

Chapter-1: Introduction

This chapter provides the insights about the importance of advance manufacturing technology in today's competitive and dynamic market scenario. This chapter also presents the research questions and purposes of the study.

Chapter-2: Literature Review

It presents the literature review of advanced manufacturing technologies, barrier multi criteria techniques, benefits, relationship of AMTs with supply chain innovations and sustainability.

Chapter-3: Research Methodology

This chapter provides the overall research flowchart for conducting this study. It includes nature of research, research procedures, research design, questionnaire development, steps involved in GTMA, AHP, fuzzy-TOPSIS, and SAP-LAP approach.

Chapter-4: Justification of AMTs

This chapter discusses the advantages of AMTs over conventional manufacturing system. Analytic Hierarchy Process (AHP) was applied to calculate the weights of various performance parameters.

Chapter-5: Barriers of Advanced Manufacturing Technologies

This chapter presents the various barriers associated with adopting AMTs. Graph Theoretic Approach (GTMA) was used to compute the intensity and permanent function value of various anticipated barriers

Chapter-6: Critical Success Factors of Advanced Manufacturing Technologies

In this chapter, we presented various CSFs for AMTs adoption patterns in industries. The CSFs are mapped with performance parameters and ranking is done using fuzzy-TOPSIS approach

Chapter-7: Case Studies

This chapter discussed the case studies of adopting AMTs in Indian manufacturing industries, its challenges and SWOT analysis.

Chapter-8: Conclusion and Implications

This chapter describes the conclusions of the research and key findings. It discusses the implications for researchers and corporate professionals. The limitations and future scope are also listed.

1.7 Concluding Remarks

It is found that there are limited studies are available pertaining to identifying challenges for AMT adoption in India. Therefore, next Chapter discusses about the literature in context of challenges, critical success factors for adopting AMTs in emerging economy context. Moreover, these were analyzed using various MCDM techniques such as AHP, GTMA, TOPSIS.

Chapter-2: Literature Review

2.1 Introduction

Technology have completely revamped the whole society. With the passage of time, there is tremendous change in processes of manufacturing goods and delivering services. Intensified competition has put the manufacturing industries under high gravity in the past few years. Extensive changes are happening in the manufacturing section through industrial revolutions, starting with the steam evolution in the first industrial revolution to cyber-physical system-based manufacturing in the fourth Industrial revolution (Wamba and Queiroz, 2022; Vinodh et al., 2023). To bear the competitiveness, Indian industries are highly reluctant to invest in technological innovations. Adopting contemporary technologies and innovative practices is the backbone for socioeconomic prosperity. Therefore, Industry 4.0 is an emerging area of research (Zheng et al., 2021; Xian et al., 2023). Lahane et al. (2023) discussed applications of Industry 4.0 in food supply chain so that vision of Swachh Bharta and Digital India can be met. Adopting Advance Manufacturing Technologies (AMTs) is reported to enhance performance significantly. There is widespread usage of robotics and automation in different industrial sectors, including manufacturing, automotive, healthcare, and construction. Adoption of AMTs is helping industries to grow faster and thus adding to the progress of the nations. A study by Kamble et al. (2018) reported that investment in advanced technologies brings fruitful results. Another similar study by Bag et al. (2020) presented that operational and tactical strategies focused on high-quality products and services are essential for organizational excellence.

Furthermore, AMTs are a combination of technologies that must be designed, developed, implemented, and assessed for higher performance and efficiency. Despite the benefits as discussed, Industry 4.0 have many cons. The physical equipment is connected over wireless networks using IoT protocols, so the data and information systems are susceptible to cyber security concerns (Sony and Naik, 2020).

Countries across the globe are taking a large number of initiatives towards adopting AMTs. Although the implementation of AMTs is subjected to complex systems involving various internal and external factors, results after implementation are appreciable. Because of its marvelous performance, the manufacturing segment is also termed a sunrise sector in the Indian economy. The Indian manufacturing segment is one of the booming sectors across the world. Indian Government has huge funds (US$ 104.25 million) allocated for promotional activities of manufacturing, Electric vehicles, and Electronics and IT (IBEF, 2022). India is expected to become the hub of globalized manufacturing by 2030. To make India self-reliant, various policies and incentive schemes have been initiated. The five pillars of self-reliant India include exponential economic rise, optimum utilization of resources, digital transformations, high-end infrastructure, and strong democracy. Some of the objectives of this campaign include professional training, promoting education and developing skill sets, and women empowerment (IBEF, 2022). Also, the Government announced a production-linked incentive scheme to enhance the employability of people. So, the presented literature talks about several aspects of implementing AMTs, including benefits, challenges, and critical success factors. Also, managerial, social, and practical implications are discussed for researchers, academicians, practitioners, and industrialists.

Dangayach and Deshmukh (2005) categorized the advanced manufacturing technologies in to Direct, Indirect and Administrative. It caught the attention of industry managers because of plethora of benefits. Direct AMTs are typically hardware based including Computer Numerical Control (CNC), Robotics, Automation, Flexible Manufacturing System (FMS), Automatic Storage and Retrieval System (AS/RS), Automated Guided Vehicle (AGV). Whereas Indirect AMTs encompasses Computer Aided Design (CAD), Material Requirement Planning (MRP), Statistical Process Control (SPC) etc. Furthermore, Administrative AMTs presents the organizational help to carry out different functions which includes Enterprise Resource

Planning (ERP), ABC analysis. A new advanced manufacturing technology concept Industry 4.0 is coined by Germany in the recent times (Year, 2011) supported by various highly advanced and digital technologies (Ozkan-Ozen and Kazancoglu, 2021). It helps to access real-time monitoring and control of manufacturing operations, thus higher autonomy and strong interaction among stakeholders. Ghobakhloo (2020) highlighted that there is exponential rise in usage of Industry 4.0 technologies. It is redesigning the way people work and interact necessarily. Also, Dalenogare et al. (2018) discussed Industry 4.0 implementation as a hit instead of hype. As Industry 4.0 technologies are capital-intensive, there is a need to innovate cost-effective technologies so that industries can also take initiatives towards its implementation (Dixit et al., 2022).

2.2 Types of AMTs

In this section, the AMTs are classified as Direct AMTs, Indirect AMTs and Administrative AMTs.

2.2.1 Direct AMTs

Direct AMTs play a crucial role in the production process and the final product shape because they physically modify raw materials to make completed goods. These technologies includes CNC, DNC, Robotics etc . The Direct AMTs are classified as follows:

Computer Numerical Control (CNC) Machines: It deals with automation of machine tools by using programmable instructions consisting of G & M codes (preparatory and miscellaneous codes). These machines were introduced in early 1970s. Prior to that Numerical Control (NC) was introduced in year between 1940s and 1950s. The basic mode of operating NC machine was punched tape, which was fragile. The instructions were coded there in the form of holes and spaces. Also, for alteration in product design, punched tape was supposed to be developed again, which was tedious and time-consuming process (Li et al., 2020).

Keeping in view these flaws of NC machines, CNC machines were introduced. The CNC machine was able to reprogram the coded instructions for any change in product design within no time. Also, the other advantages of CNC machines include low energy consumptions, enhanced worker safety, faster production, zero defects, less wastages (Lv et al., 2016). Liu and Xu (2017) discussed that CNC machines are not compatible in coordination with Industry 4.0, thereby introducing the concept Machine Tool 4.0.

Direct Numerical Control (DNC) Machines: The other name of Direct Numerical Control is Distributed Numerical Control (DNC). In this, different CNC machine tools are connected to a central computer thereby allowing the machines to have a large database (Adu-Amankwa et al., 2019). Using DNC, the same part program can be run on different machine tools simultaneously thereby reducing time and cost (Xiang et al., 2016).

Robotics: Robotics are being considered as game changer in the manufacturing landscape. It has impacted largely to the productivity and industry performance (Ballester et al., 2021). Although some researchers raised concerns about the costs and future employment as the social implications of adopting robotics. Robots are found to be versatile machines suited for handling various complex tasks in various industrial sectors including manufacturing (Bhatt et al., 2020), healthcare (Johnston), hospitality and tourism (Goel et al., 2022), construction (Pan et al., 2022). Bhatt et al., (2020) discussed the role of robotics in additive manufacturing, where robots help in formation of multiple layers of materials, investigating the relevant constraints associated with technicalities, formulating the foundation for algorithm and enables automatic profile generation.

FMS: FMS enables the manufacturing system to produce a variety of product components using same manufacturing facility thereby optimizing the resources including space, time, manpower, machine, and others (Reddy et al., 2021). Sarkar and Bhuniya (2022) discussed the role of FMS in achieving sustainability and conserve the environment. The authors also mentioned that supply chain becomes smarter after implementing FMS so that fluctuated customer demands can be timely met.

Automated Material Handling Systems (AMHS): AMHS is highly connected to meet Industry 4.0 based smart manufacturing (Chien and Hong, 2022). This material handling is based on established base automation technologies and a standardized wireless network. The AMHS congestion can be significantly reduced by using simulation, machine learning and effective dispatching system (Chien and Hong, 2022).

Automated Guided Vehicle (AGV): Unmanned vehicle including AGV are high importance to enhance efficiency of logistics system (Oyekanlu et al., 2020). Decentralized systems help in enhanced flexibility and scalability in the manufacturing system (De Ryck et al., 2020). These play very crucial in todays globalized logistics system. Industry 4.0 have urge the AGV manufacturing industries to adopt innovative solutions for solving complex issues (Lu et al., 2017). Primarily AGV tasks can be bifurcated into five major domains i.e. work assignment, steering task, path defining, motion planning and control, effectively managing vehicle (De Ryck et al., 2020). Also, 5G have strong role in effective fleet management of AGV and its scheduling (Oyekanlu et al., 2020).

AS/RS

It is one of the most popular technologies of smart warehouse automation and management system (Chen et al., 2022). Some of the benefits of using AS/RS includes effective utilization of space, enhanced inventory storage capacity, reduced worker cost, improved accuracy and security. Mondal et al., (2022) discussed the applications of machine learning algorithms for handle large variety of products in smart warehouse. These systems are found to be energy intensive which can be overcome by optimization in multi-shuttle AS/RS (Yang et al., 2018).

2.2.2 Indirect AMTs

With an emphasis on optimizing processes without directly influencing the final product, indirect manufacturing technologies are crucial to the optimization of the production process. Their main focus is on improving efficiency by controlling and supervising different aspects of the manufacturing environment. The Indirect AMTs are classified as follows:

Computer Aided Design (CAD)

CAD makes use of software in product design and development (Delera et al., 2022). It optimizes the designer's work, reduces cost, is flexible, and enhances the quality of design and documentation. It is used in a variety of professions including engineers, scientists, researchers, architects, product designers, manufacturers, interior designers. Some of the commonly used packages are AutoCAD, Creo, CATIA, SOLIDWORKS, Micro Station.

Material Requirement Planning (MRP): Handling uncertain demand and effective production planning and control are very much essential in organization (Guillaume et al., 2017). These uncertainties quite often raise the concerns of bullwhip effect and high risks in supply chain. To tackle these issues, MRP is very useful technique to investigate the quantity of material and other components needed to manufacture products. Some of the benefits of MRP includes uninterrupted flow of production, reduced inventory, enhanced customer satisfaction, and reduced customer lead time.

Statistical Process Control (SPC): In today's competitive world, manufacturing high quality and increased reliability products and services are extremely significant in each and every organization (Asadzadeh, 2022). As the name implies, it is concerned with use of statistics to control production procedures and maintain the quality of products and services. Tegegne et al. (2022) uses SPC in cement manufacturing plant and concluded that SPC is basis for advanced process control.

Bar Coding: Itis a technique for automatic collection and recording of data from various operations in organizations including production, quality control, inspection, packaging and distribution. Due to its potential benefits, it is most widely accepted in various business organizations. It is simple method of encoding the text information using cost-effective electronic scanners (Jones et al., 2022). For example: chemist while selling the medicines can trace the present inventory and share the data using Electronic Data Interchange (EDI) to suppliers so that replenishment can be done on time. Goh et al. (2016) used bar code based system to maintain supply of sterile supplies in hospitals.

Manufacturing Resource Planning (MRP-II): Mass customization has emerged as pivotal approach to produce customized products and satisfy the customers as an individual (Dean et al., 2008). Furthermore, it is very significant to maintain the superiority of the products and services. Because of large variety of components and products, conventional method of managing inventory is not effective. Therefore, MRP-II is the technique for effectively and effectively managing the organization's resources (Marsh et al., 2014).

2.2.3 Administrative AMTs

The foundation of effective management, planning, and coordination in manufacturing operations is provided by administrative AMTs, which are also essential for optimizing overall business processes and making well-informed decisions (Sislian and Jaegler, 2022). These technologies include integrated software programs, such as Enterprise Resource Planning (ERP), which allow for the thorough control of orders, inventories, production scheduling, and financial aspects. Systems for product lifecycle management, or PLM, are essential for managing a product's whole lifecycle, from development and design to production, sale, and disposal (Charaf et al., 2022).

Enterprise Resource Planning (ERP)

ERP concept is very widely used to maintain a centralized database of data and information which can be accessed by individual depending on the authority given. The different modules in ERP are inventory management, supply chain management, workforce management, finance, manufacturing, marketing etc. (Carlsson-Wall et al., 2022). Sislian and Jaegler (2022) discussed the role of Blockchain integrated ERP for enhancing sustainable performance.

Activity Based Accounting Systems (ABAS): There is always a challenge before manufacturing industries to select an appropriate accounting system (Monoroy et al., 2014). The authors discussed the relevance of lean accounting in the value stream and activity-based costing system for effective decision making. ABAS helps the organizations in continuous performance improvement and profitability (Charaf et al., 2022). Zafarzadeh et al. (2022) used systems dynamic approach for modelling activity-based costing for managing university funds.

Office Automation

It implies integration of computer hardware, software and office processes.

2.3 AMTs Implementation Steps

The AMTs implementation steps includes planning and justification, pre-implementation phase, and post-implementation phase. The steps are explained as follows:

Planning & Justification: Strategic planning and justification is required to take effective decisions. The emergence of technological innovations must be propagated through strategic change in existing processes which ensures effective AMTs implementation. Planning also include the selection of proper technology as per the requirements and choosing the right suppliers (Bhise and Sunnapwar, 2019). Proper analysis of strategic issues helps the organizations to identify the mitigation strategies to tackle these issues.

Pre-Implementation Phase: AMTs implementation is complex and cumbersome until the proper planning is not made in pre-implementation process. This phase analyze the various aspects of AMTs implementation including change management, required support, sensitization programs, supplier selection, involvement of external consultants (Goh et al., 2016).

Post-implementation phase: It includes the actions done after installation of AMTs. It may be the case that employees are uncomfortable to advanced systems, working with advanced technologies. To tackle these issues, periodic training and educational programs can be highly helpful. Also, proper monitoring and control of equipment help to track AMTs and take corrective action in case of any anomalies (Marsh et al., 2014).

2.4 Benefits of AMTs

- As the present market scenario is characterized by high competition, and uncertain customer demand, adopting AMTs helps to meet these objectives and reduce lead time considerably.
- Highly automated and advance manufacturing set-ups helps to reduce the changeover time thus facilitates machine performance and uninterrupted flow of production.
- Improved quality of products with close tolerances results in enhanced customer satisfaction, which ultimately results in more customer satisfaction, increased sales and profitability of organization.
- The data and information can be shared in a centralized manner using ERP, which makes better control of manufacturing operations.
- Technological advancements enable the business processes to know the market demand requirements more precisely, thereby helps to have better control over inventory.
- Predictive maintenance assists the managers to know the maintenance schedule in advance, thus helps to almost eliminate the machine breakdown time.

- Introducing digital technologies in the automotive sector helps in better human-computer interaction and resulted in effective decision making.
- AMTs in automotive sector make the organization highly agile, flexible and responsive to changing demand patterns.
- Since AMTs are low energy consuming equipment, therefore, it results in energy saving and helps to achieve sustainable development goals.

Table 2.1: Studies related to Advanced Manufacturing Technology Adoption

S.No	Author (Publication Year)	Key Findings	Method Used
1	Kamble et al. (2018)	The new digital revolution is characterized by automation of distinct production processes and give the emergence of smart factory. Various aspects are integrated with intelligent networks based on cyber-physical system, resulting in exponential increase in productivity and efficiency.	ISM
2	Raj et al. (2019)	Industry 4.0 is a burgeoning approach, capable to restructuring the entire operations, and facilitates decentralized control of production. As a result, it is able to integrate various stakeholders i.e. people, equipment, data and information for enhanced agility, flexibility and responsiveness.	Grey-DEMATEL
3	Ramos et al. (2022)	The advent of industrial revolutions have transformed the requirements in terms of skills, abilities, and experience and education level.	Conceptual
4	Hopkins (2021)	Some of the advantages of implementing Industry 4.0 in supply chain include more connectivity, transparency, traceability. It also facilities in real-time monitoring, and better forecasting and customization.	Conceptual
5	Hu et al. (2020)	The connection between Green Industrial Internet of Things (GIIoT) and sustainability was investigated. It is found that motivation, responsiveness, efficiency and effectiveness plays a significant role.	Empirical
6	Wang et al. (2022)	Various constructs like Design AMTs, Manufacturing AMTs and administrative AMTs, product innovation	Empirical

		management, design-manufacturing integration were discussed based on knowledge-based theory.	
7	Storenelli et al. (2021)	AMTs facilitates higher level of equipment connectivity and ensures optimum planning and utilization of resources. It also helps to develop sustainable business models for growth and competitive advantage	Systematic Literature Review
8	Chang and Wang (2009)	Seven critical factors for AMTs implementation was assessed, committed sponsorship, operating sponsorship, think-link relationship, strategic business alignment, collaboration with present system, organizational interface, manager commitment.	Analytic Hierarchy Process (AHP)
9	Chauhan et al. (2021)	Barriers of Industry 4.0 were investigated using structural equation modeling approach and AMOS. The research results highlighted that Industry 4.0 helps in enhancing supply chain competitiveness and organizational effectiveness.	Empirical
10	Sony and Naik (2019)	Organization readiness towards Industry 4.0 implementation were analyzed on the basis of various parameters. These includes top officials support and commitment, strategic alignment and readiness, employee skillsets, level of automation, intelligent products and service.	Conceptual

2.5 Role of Advanced Manufacturing Technologies in achieving Sustainable Development Goals (SDGs)

Focusing on sustainability aspects by manufacturing organization is highly essential, but is neglected (Yadav et al., 2020). Additionally, Bai et al. (2020) discussed the role of AMTs in sustainable society. AMTs have crucial role not only in enhancing competitiveness but act as strong facilitator in achieving sustainability (Jin et al., 2017). New advancements in manufacturing led to greener materials, new analytical models for process control and optimization (Hu et al., 2022). The work processes including project planning and scheduling, facility layout and design, quality and inventory management have a profoundly improvement by adopting AMTs. The research results provided by Huang et al. (2016) indicates that approximately 33-50 % of energy is conserved by using additive manufacturing technologies. Also, the research performed by Bai et al. (2020) highlighted the greatest influence of digital technologies including nanotechnology, drones on11 sustainability in automotive, apparels, and electronics sector. Various challenges are found by organizations in adopting sustainable practices. Tortorella and Fettermann (2018) discussed that the success rate of achieving sustainability by adopting advanced manufacturing technologies is higher in developed countries in contrast to developing ones. The possible cause could be lack of available resources, lack of skilled manpower, lack of funds and lack of top management commitments in developing nations. Similarly, findings were reported by Moeuf et al. (2018) and Yadav et al. (2020).

2.6 Human-Aspects in Advanced Manufacturing Technologies

It is seen that human-aspects are highly neglected in various research studies. The advanced automation including sensors, actuator and other advanced equipment being having self-optimizing from learning experience (Kamble et al., 2018; Luthra and Mangla, 2018). Also, the authors stated that employees lack advanced skillsets to work in highly digitalized scenario. It is still ambiguous to report to highlight the required skillsets in Industry 4.0 environment. Requirement to explore the changes between present and required skill sets in AMTs was highlighted (Ozkan-Oze and Kazancoglu, 2021). Islam (2022) highlighted the business skills (critical thinking, cognitive ability, business problem solving, and communication) and technical skills (programming, quantitative, data visualization and interpretation) skills are required. Romero et al. (2016) discussed the concept of human-cyber physical system interaction, in which operator 4.0 will be operating in Industry 4.0 environment. The authors discussed that Industry 4.0 is going the change the role of operator and augment the performance of employees. Ozkan-Ozen and Kazancoglu (2021) analyzed the challenges for workforce development, lack of analytical and creative thinking is found to be a potential roadblock for advanced manufacturing technology adoption. Ramos et al. (2022) investigated the labor requirement depends on level of automation, labor demographics parameters. The authors concluded that as the age of labor increases, the chances of automation of work increases. Another study by Low et al. (2019) in Singapore assessed the expectation of employers and discussed that fresh graduates lacks soft skills required to adopt AMTs. The function of cyber-physical machine tool is shown in figure 2.1.

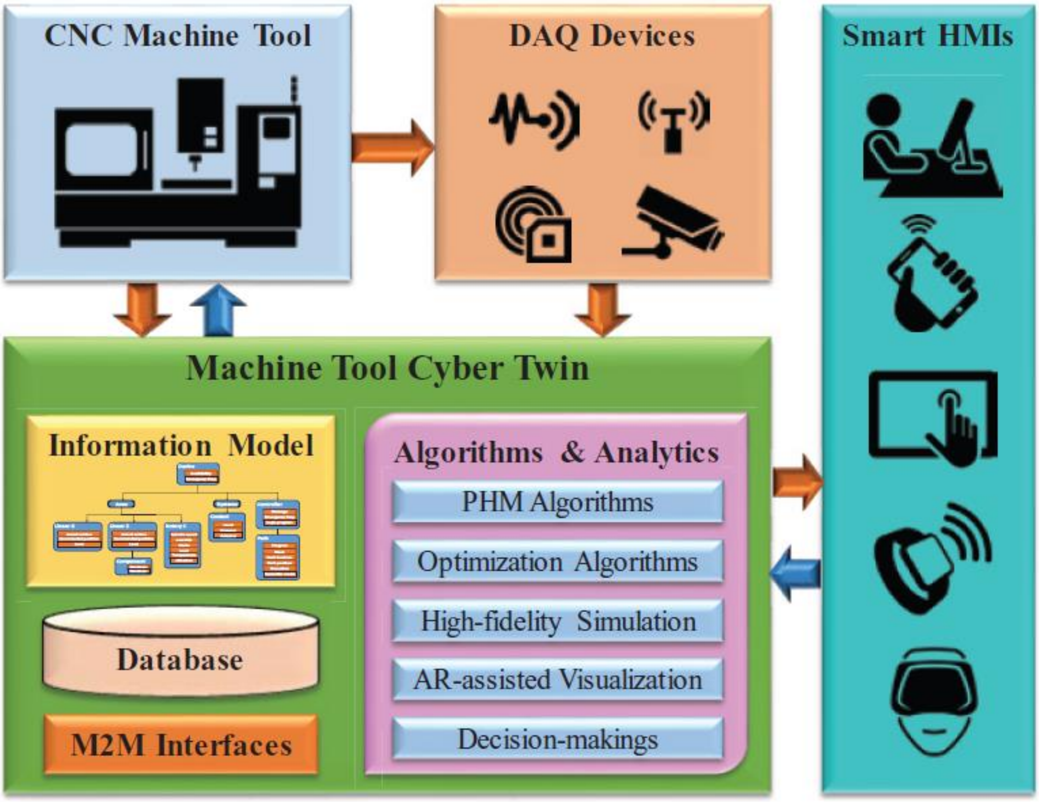

Figure 2.1: Function of Cyber-Physical Machine Tool (Liu and Xu, 2017)

2.7 India Readiness towards Advanced Manufacturing Technologies

The government of India (GoI) is taking strategic initiatives to grow from 16 % to 25 % of GDP for the manufacturing domain. Many initiatives are being taken for "Make in India," and under this, AMTs are being focused upon much. India, including other countries, is putting rigorous efforts into adopting AMTs. Industries are well aware that providing quality products to customers is essential while reducing defects, wastages and scraps. AMTs play a highly important role and strengthen industries' capability. Adopting cutting-edge technologies gives India a strong foundation to enhance performance levels and customer engagement.

Furthermore, AMTs are highly supportive to optimize and streamline production processes. However, as highlighted in scholarly literature, adopting AMTs is subjected to many obstacles. Therefore, the presented study identified significant anticipated barriers to successful AMTs adoption. These barriers must be assessed properly, and strategies must be designed to overcome them comprehensively. Moreover, understanding the CSFs of AMTs provides managers with crucial insights about the required direction. Accordingly, industries can analyze their position relative to other players in the same area.

India including other countries are still in introductory phase of AMTs adoption. In Deloitte Annual Survey (2020), 2000 top officials were interviewed from 19 countries across the globe. As per report, only 17% of CXO consider investments in Industry 4.0 technologies as a priority. India is adopting various countries strategic tools and techniques to adopt advanced manufacturing technologies. Under the mission "Samarth Udyog Bharat 2.0", use of various digital technologies in manufacturing processes including Artificial intelligence, Internet of Things (IoT) and other associated technologies is highly promoted. These technologies facilitate optimization of resources and reducing the wastages. Various technical centers like Centre for Industry 4.0 lab (Pune), IITD-AIA Foundation for Smart Manufacturing, I4.0 India at IISC Factor R& D platform, Smart manufacturing demo & development cell at CMTI, I4.0 projects in advance manufacturing, IIT Kharagpur are initiated.

Business processes are growing faster with the inception of advanced technologies, attracting a lot of job prospects and training requirements. Intensified competition from the stakeholders urge the businesses to explore the strategies to make steadiness between 'profit and purpose'.

Many business leaders focused more on profitability aspects but as transformations progressed, a larger picture of responsibility was felt by corporate professionals (Renjen, 2020).

2.8 Applications of Advanced Manufacturing Technologies

In today's turbulent environments of globalization and progressive advancements, manufacturing industries are facing a lot of challenges (Zheng et al., 2021).

New Product Development (NPD): Wijewardhana et al. (2020) discussed the role of Industry 4.0 in new product design and development. Various stages of NPD including analysing customer expectations, examine past data and information, concept clarity, rapid prototyping, feedback loop, doing alterations and adjustments, can be better visualized and assessed using AMTs. A similar study by Arromba et al. (2021) discussed that Industry 4.0 is highly beneficial for the organization to develop new products.

Process and People Safety: Handlingsafety concerns is ofutmost importance for manufacturing and process organizations (Lee et al., 2019). It is a high time to understand the concept of employee 4.0 and safety 4.0 (Gajek et al., 2022). Improved operator simulator interface, digital visualization, and intelligent alarm monitoring system reduced the accidents and fatalities enormously (Lee et al., 2019). Junior et al. (2022) done the cluster analysis for

Facility Management: AMTs helps in better utilization of facilities, lower operations costs, enhanced workplace experience, enhanced asset reliability and safety, vendor assessment and association (Chen et al., 2020). In order to accelerate growth and staying competitive, organization are embarking advancements in production facilities by adopting AMTs (Kerin and Pham, 2019).

Production Monitoring: Meyer et al. (2011) and Rodrigues et al. (2022) presented the importance of digital transformation in production monitoring and control. In today's globalized scenario, real-time production monitoring and control is done using IoT devices, smart sensors, artificial intelligence. Machine learning etc. Ayvaz and Alpay (2021) discussed the role of machine learning approaches to analyze data from IoT devices. This helps the production managers to analyze potential failures in advance so that necessary steps can be taken accordingly to prevent machine downtime.

Operator Monitoring: This is other crucial aspect of smart manufacturing system. Machines are capable enough to record unawkward postures of employees so as to prevent Musculoskeletal Disorders (MSD). With the introduction of fourth industrial revolution. Human-machine interaction is now changed to Human-cyber physical interaction. Costa et al. (2022) discussed the role of augmented reality in human-robot interaction to enhance human factor efficiency.

Faulty Prediction: The anomalies in the equipment calls for maintenance in advance to prevent breakdown and unnecessary delays in production. Timely maintenance has a pivotal role in enhancing business performance. Even delays and downtime for couple a minutes are considered as huge loss to the industries. The predictive analytics helps the industries to plan their maintenance schedules well in advance. Lv et al. (2022) used digital twin and deep learning network analysis is highly accurate in zero-defect manufacturing systems.

Remote Asset Management: Use of automation technologies in the digital world are spreading like anything. Since the industries are making huge investments in AMTs, proper asset management is highly crucial. Advanced technologies including Digital twin have come-up with innovative solutions for remote asset management (Errandonea et al., 2020). This factor creates a leap impact in having a competitive edge over other counterparts in the dynamic market. It enables decentralized database and use data analytics capabilities to track the performance of assets using smart sensors and IT technologies. It results in drastic improvement in Overall Equipment Effectiveness (OEE) which is importance measure of plant performance.

2.9 Barriers of Adopting AMTs

The barriers of adopting AMTs are classified as Technical and informational barriers, Operational and strategic barriers, Financial and Economic barriers (FEB) and Human Barriers (HB).

2.9.1 Technical and informational barriers (K_1)

These barriers are connected to the knowledge of the AMTs theories and conventions. According to Silva et al. (2013), the deficiency of organizational competence decreases the encouragement for training, higher management administration, employee involvement and the existence of precautionary communication and actions to implement AMTs. Dubey et al. (2017) have observed that managers should continuously upgrade skills and capabilities of workforce to achieve sustainability in operations. Limited technical know-how and information about viable AMTs have worked as major obstacle in its implementation (Van Berkel, 2006). According to Shi et al. (2004), lack of technological practice on the workshop floor, additional infrastructure requirements and inadequate approach to extrinsic technological base. Lack of effective training programs and weak management approach can cause employees less involved in the manufacturing processes or decision-making approach towards the AMTs adoption, thus making the implementation process relatively slow or less efficient. AMTs awareness campaigns for industry, government, funding agencies, banks and the public are scarce. Many times, the stakeholders are involved in the concept of AMTs adoption but are incapable to put it in practice, due to information gaps and lack of technical assistance (Gunningham and Sinclair, 1997). Lack of consciousness and keenness is the dominant problem in the application of AMTs (Attri et al.2012a; Baglee and Knowles 2010). Less skilled workforce and lack of technical knowledge also disintegrate the AMTs implementation efforts. A critical obstacle refers to inadequate information about expense of energy redeeming technologies (Tonn and Martin, 2000).

The obstacles for high energy efficiency during establishment of industry are due to lack of technological knowledge, deficiency in laboratory and checking equipment (Zilhay, 2004). Lack of training is responsible for poor knowledge about AMTs (Mitchell, 2006). People without sufficient technical skills make decisions without adequate information (Trianni and Cagno, 2012). Besides, the lack of technology, the absence of appropriate infrastructure and low technical ingenuity can also create an immense objection in complying the environmental legislation, and eventually influence the performance level in adopting the AMTs adoption (Moors et al. 2005).

Table 2. 2: Different categories of barriers in adopting AMTs

S.No	Barriers of AMTs	References
1	**Technical Information barriers (TIB)**	Gunningham and Sinclair (1997), Mitchell (2006)
	Lack of access to external technical support and knowledge	DeCanio (2012), Zilhay (2004), Mitchell (2006)
	Lack of awareness about technologies and industrial revolutions	Attri et al.(2012), Baglee and Knowles (2010)
	Lack of upgradation of machines and tools	Attri et al.(2012a); Baglee and Knowles (2010),Tonn et al. (2000).
	Lack of skilled workforce	Tonn et al. (2000), DeCanio (2012), Zilhay (2004)
2	**Operational and strategic barriers (OSB)**	Mittal et al. (2013), Mittal and Sangwan (2011), Shi et al.(2008)
	Lack of support for technology innovations	Mittal et al. (2013), DeCanio (2012), Kablan(2003), Zilhay (2004), Moors et al. (2005)
	Lack of awareness of sustainable operations	Mittal et al. (2013), Mittal and Sangwan (2011)
	Lack of sustainability measures	DeCanio (2012), Kablan (2003), Zilhay (2004), Moors et al. (2005)

	Lack of long-term planning	DeCanio(2012), Kablan (2003), Shi et al.(2008)
3	**Financial and Economic barriers (FEB)**	Shi et al.(2008), Mittal and Sangwan (2011)
	Lack of dedicated financial budget for technologies	Jaffe and Stavins (1994), De canio and Watkins (1998),Baglee and Knowles (2010)
	Difficulty in accessing financing	Jaffe and Stavins (1994), De canio and Watkins (1998), Hafez (1994), Zilhay (2004)
	Lack of economic incentive policies	Hafez (1994), UNIDO/UNEP, 2004), Mittal and Sangwan (2011)
	Lack of internal accounting and auditing	(UNIDO/UNEP, 2004), Mittal and Sangwan (2011)
4	**Human Barriers (HB)**	Vickers et al. (1999), Haris et al.(2000), Kablan (2003).
	Difficulties linked to new learning processes	De Grot et al. (2001), Lopes et al. (2013), Ahuja and Khamba (2008)
	Lack of fear of government regulations	Haris et al. (2000), Kablan (2003), Ahuja and Khamba (2008), Vickers et al. (1999)
	Lack of involvement of work force	Ahuja and Khamba (2008)

2.9.2 Operational and strategic Barriers (K_2)

These barriers are associated to the operational procedures along with key judgement of the application of AMTs. It involves possibilities of process conversion, equipment restoration or product/packaging redesign. The probability of the rejection of the product increases due to poor working environment, implementation of traditional tools and techniques, poor control and monitoring.

Poor monitoring is one of the main challenges to AMTs application. Industries consider monitoring to be unnecessary and this result in the lack of predictable data. Without acceptable data about operating parameters and material flow, successful adoption of AMTs is not desirable in the long run. Although this does not require major expenditure, but it needs resources in the form of time and trained manpower. According to Mittal et al. (2013); Mittal and Sangwan (2011), AMTs lag due to inadequacies in periodic maintenance program, the poor atmosphere of the organisation, insufficient utilization of machines, methods and techniques like TQM, 5S etc. Having outdated machines or second-hand machines are another hurdles. Other possible hurdles include lack of tangible areas (Kablan 2003; Zilhay 2004). Strategic planning of implementation of AMTs assesses what could go inaccurate, conclude important uncertainties, and hold good approaches to accord with those risks.

2.9.3 Financial and Economic Barriers (K_3)

Financial and economic barriers are those which have high cost of capital. Hence it leads to poor performance and lack of effective performance measurements for AMTs (Shi et al. 2004). Energy efficiency gaps due to financial, economic and market factors stop manufacturing sector from immediate spending in energy saving technologies. Finite approaches to capital may restrict energy effectiveness estimates from being carried out (Jaffe and Stavins 1994; De Canio and Watkins 1998). There are no competent funds or incentives or loans from banks or other financial institutions, which helps the industries to encourage the adoption of AMTs. In developing countries, a major obstacle with the adoption of AMTs is lack of funding resources both externally and internally. Upfront funding is required to establish the most basic prerequisites of a AMTs adoption, but the investment is less alluring when the benefits appear only in the long term. Banks are cautious about funding projects, and they find it difficult to calculate in terms of economic soundness (Hafez, 1994). The lack of ability to designate the sufficient budget and resources could cause the manufacturer always to lag behind in terms of AMTs application.

The implementation of AMTs has been precluded by a lack of access to finance. Banks, government investment agencies, corporate financial departments, venture capitalists, and other sources of risk capital for industry either discriminate against or do not have the competence to evaluate applications that concern AMTs, thus severely limiting their access to capital. Accounting systems and project appraisal procedures very often decline to take sufficient account of environmental impacts, uncertainties, liabilities and associated expenses (which are not easily quantifiable to start with). Because of these limitations, the stakeholder is often incapable to place environmental performance in the business perspective and therefore fails to fully acknowledge the economic benefits of adopting (UNIDO/UNEP, 2004).

2.9.4 Human Barriers (K_4)

These barriers are connected to the culture dominating in the manufacturing sector, that extremely influence the functioning of human resources within the organisation. Inadequate eagerness of human resources to accept AMTs are major issues in the Indian organisations. These barriers are related with principles, attitudes and ideas of human resources that promote the work fashion. Sarkis (2018) has observed that to facilitate sustainability in operations, organizations should embrace socially friendly principles, attitudes and behaviour. Top management is key behavioural factor in handling different human barriers (Muduli et al., 2013)

For the productive application of AMTs, the authority must take responsibility of staff members' ideas and work atmosphere among others. This problem can be handled by the empowerment and encouragement of employees. Vickers et al., (1999) have observed that the endorsement of top management is mandatory for the successful adoption of AMTs so that the enterprise is allocated with adequate resources, manpower, time and access to the information. AMTs options emphasize more on people changing their attitudes and habits rather than firms changing technology. Many stakeholders have an attitude to follow business as usual and not adapt to change. Any change is considered as unwarranted, risky and not necessarily profitable.

Some organisations deny to technological alterations because they are unaware how to hold good energy preservation program or how to appraise energy savings assistances (Haris et al. 2000; Kablan (2003). Relatively stringent organisational barriers are faced by more competitive manufacturing sectors (De Grot et al., 2001). Furthermore, Ahuja and Khamba (2008) have described inadequate encouragement and approval to the employees as the hurdle in Indian production systems.

Sixteen barriers for implementation of AMTs are identified from the literature. Based on literature and experts' opinion, these barriers are classified into four categories. There are several characteristics that differentiate this study from the past studies of AMTs. This research is designed to find the prioritisation and index value of the barriers in a quantitative way. Former studies of AMTs barriers have analysed range of barriers without prioritizing and ranking them. According to Shi (2003), manufacturing industries face major challenges in adopting AMTs because they are mostly confronted with punitive measures rather than supportive and inducing policies.

2.10 Critical Success Factors of AMTs

Advanced manufacturing technologies is found to contribute enormously in enhancing the operational performance of the organizations. As the market is highly dynamic, it is extremely important for the organizations to be agile, flexible and responsive to satisfy customer changing requirements.

Skills and Expertise development to implement AMTs

With the advent of contemporary technologies in the globalized manufacturing landscape, the requirement of skills has been changed drastically (Kamble et al., 2018). To cope up with these changes, employees are required to sharpen their skills sets to flow in a competition stream. It is highly essential to survive in the marketplace. As digital revolutions are taking place, role of operators is changing i.e. in the current scenario, smart operators are required. Additionally, Kumar et al. (2017) stated that emergence of information and data analytics technologies have called for new set of engagement and expertise. For the success of AMTs in any organization it is crucial that the employees are well trained and know about the critical aspects, for that the organizations need to conduct training sessions of regular interval to build a better base for the organization and coping with the current market demands and scenarios. The role of top management plays significant role in it, it should motivate the employees of the training and developing the skills and show them how these skills are going to be a part of the industry in near future.

Readiness for organizational change to adopt AMTs: The senior officials should understand the market demands, how the technology is changing and how it is going to be beneficial for the organizations (Singh and Gurtu, 2021). By looking at the future needs and the demands of the market they should prepare for the change and should be agile with it. A lot of organizations have failed as they were not able to cope up with the changing market and the customer demands.

Organization Culture

Organization culture have momentous effect in transitioning to advanced manufacturing technologies. Positive vibes of organization help to motivate the employees and keeps them intact towards their work. Parent and Lovelace (2018) described synergetic relationship between organization culture and employee involvement. Similar results were reported by Nan et al. (2020) who analysed employee engagement in industries. Da Rosa et al. (2012) mentioned the role of structured organization and teamwork capabilities for implementing AMTs.

Top Management Commitment

Susceptibility of AMTs calls for examining, evaluating, developing and implementing various key aspects (Kumar et al., 2017). Various researchers (Dean et al., 1992; Sambasivarao and Deshmukh, 1995) have discussed the impact of top management commitment leadership style on overall efficacy in implementing AMTs. It is highly significant factor which facilitates in leading digital transformation, provide required resources, funds etc. Furthermore, Kumar et al. (2017) highlighted that top management helps by sharing their knowledge and experience. The top management or the champions are the influencers, whatever the champion's motivation, the onerous responsibility of an AMTs assures that senior management will go to great lengths to fulfil the board's operational goals.

Educational & Training Programs

The need of educational and training programs in successfully implementing advanced manufacturing technologies has been raised by various researchers (Kumar et al., 2017). These type of programs helps in achieving agility so that organization must be in position to handle market dynamics and vacillating customer demands. The type of AMTs planned in particular organization decided the modules of training and educational programs (Monge et al., 2006).

Strategic Planning for Implementing AMTS: Strategic planning helps in effective and efficient utilization of resources. Efstathiades et al. (2002) reported the technovation aspects of implementing AMTs. The authors developed strategic planning model for analyzing issues emerging while implementing AMTs. Furthermore, risk assessment and mitigation strategies were properly addressed. These results were extended by Choudhry et al. (2006) who used MCDM approach for making better decision for investment concerns in implementing AMTs. This frame of view acknowledges that every technological move should have a strategic influence on the company. Changes in planned or business objectives that necessitate an examination of present manufacturing processes should prompt the need for technical advancements in production processes.

Empowerment of employees for decision making:

Empowerment helps to crate sense of belongingness among the employees (Kassinen et al., 2020). The authority can be given to trustworthy employees at least to some extent so that crucial decision s can be taken without any delays. This crucial step helps the organizations to achieve their goals and enable full utilization of human resources.

Integration and coordination among stakeholders

Cooperation among stakeholders is an important constituent of AMTs implementation. Abd Rahman and Bennett (2009) emphasized the role of buyer-supplier coordination in implementing AMTs. Coordination among the stakeholders helps to explore innovative and creative solution of given problem and manage business successfully.

Dedicated funds allocation for AMTs: Advance Manufacturing Technology is something that takes lots of efforts and commitment of the management as well as the dedicated resources in terms of time funds or may it be human resources (Raj et al., 2019). It is a long process which need continuous improvements, allocation of dedicated funds for its implementation gets crucial as the company needs to focus on long term with a vision in mind (Kumar et al., 2017).

Government policies for implementing AMTs: In every country which is focusing on implementing advanced manufacturing technology, the support of government with its laws and policies, may it be in terms of subsidies or any other kind of policies, a supporting hand of government should be there for successful implementation of AMTs in the industries (Gupta et al., 2021). Government should make policies taking into consideration about the needs of the country, company and of its citizens. AMTs can help countries increase its exports if the government come up with right policy at the right time.

Economic sustainability of AMTs: Advanced automation technologies, such as robots, are included. It is stated that there are obvious economic advantages (Kamble et al., 2018). Such as for firms it can reduce the labor cost, faster delivery, shorter lead times, a wider range of products can be created, economies of size and scalability (Ghobakhloo, 2020). Consumers, on the other hand, may benefit from it. Price reductions and greater disposable income a wider range of products to choose from, Job that is less repetitive and more interesting. In the case of the national economy, it will aid in the creation of employment and innovation in robot manufacturing, research and development, marketing, software development, and greater worker productivity with quicker economic growth.

Performance measures for monitoring and evaluation performances: A highly dedicated performance measurement and monitoring system is essential for successful adoption of AMTs(Bai et al., 2020). Doing so helps the managers to identify the bottlenecks and tackle them effectively. To safeguard your employees and your practice, evaluations should be performed fairly, consistently, and objectively.

Clear understanding of strategic goals, vision and objectives: It helps the organizations to fulfil their goals efficiently and effectively. Many experts, on the other hand, use these words "vision and mission" interchangeably. They muddled meanings and create a mess. So, it is necessary that the organization need to have a clear understanding of its vision mission and goals before it starts implementing AMTs (Raj et al., 2019).

Use of continuous improvement systems: Continuous improvement culture must be part and parcel of daily routing activities, the employees must continuously strive for adopting advanced manufacturing tools and techniques to make their process better. Continuous improvement culture helps to make the processes better, reduce defects, enhance quality of product/services, and increase organizational effectiveness (Vinodh et al., 2020).

Mutual trust and collaboration among all stake holders: No department in any organization work in silos. It is imperative for all departments to work with synergy and collaboratively to achieve organizational goals. So, starting from ideation to product conceptualization, design, development, manufacturing, and distribution of products, coordination among various linkages plays highly crucial role. Supply chain network design and optimization helps to integrate various advanced manufacturing technologies and operational excellence. Furthermore, in complicated circumstances when the new technology installation process is carried out remotely without physical interaction between team members, the lack of trust is felt even more acutely.

2.11 Performance Indicators

Cost Reduction: Cost reduction is significant criteria for selecting advanced manufacturing technologies. Although, the initial cost of the required equipment may be high, but it benefits the organizations in long run. It has been found that AMTs results in enhanced quality of products at reduced prices, better surface finish and accuracy of products.

Agility in the processes: Looking at present market landscape, customers' demands are changing in no time. Therefore, it is highly essential for the industries to become up to date in order to survive in the highly intense competitive marketplace (Kaasinen et al., 2020). AMTs is found to give satisfactory results to deal with such situations and make variety of components with increased productivity. These dedicated machine tools help to achieve flexible manufacturing system with unparalleled benefits.

Sustainable Operations: Protecting environment is one of the global challenges now a days. It is highly required for the industries to adopt greener methods of production (Vinodh et al., 2020). The components produced by AMTs are highly eco-friendly. It also produces very less wastage thereby results in reduced impact of carbon-footprint on environment. Furthermore, AMTS adoption results in increased profitability of the organizations which results in increased wealth.

Improvement in Product Quality:

The different phases of manufacturing cycle like ideation, creation, manufacturing, quality testing must be taken care off with diligence. AMTs adoption brings about using innovative ways of identifying problems and producing superior quality products in less time (Singh and Gurtu, 2021).

Resilience: Resilience implies differently in different contexts like supply chain, psychology, ecology and engineering sciences. Resilience in manufacturing implies capability to produce high quality components at economical prices in spite of inherent disturbances and fluctuations. AMTs adoption results in making the manufacturing system resilient (Peng et al., 2021). These helps to overcome the associated risks and associated losses.

2.12 Concluding Remarks

The objective of the study was to analyses different issues of AMTs implementation in Indian automotive sector. Therefore, this study exhaustive literature review was conducted. Different issues, benefits, challenges and critical success factors are discussed. Based on this research gaps and research gaps have been identified. It is identified that only few research studies are available in context of AMTs adoption in emerging economies. Therefore, future research must assess the anticipated barriers so that management can take required initiatives accordingly. Moreover, it is required to explore and investigate critical success factors for AMTs adoption so that organization can understand the key contributors and readiness towards smart technologies. In next chapter we have discussed research methodology used for this study in detail.

Chapter-3: Research Methodology

3.1 Introduction

It includes type of qualitative or quantitative data analysis to answer the research objectives (Salkind, 2010). In other words, it includes a list of statistical techniques or measures to answer research objectives. The selection of method depends on the research objectives.

Prior to start any research study, an inclusive literature review must be led to recognize research gaps in the existing knowledge or areas that require further examination (Abbott, & McKinney, 2013). Researchers then use these known gaps to develop precise research questions that they aim to address in their study.

3.2 Nature of Research

In the Research, generally two types of research are used, Inductive and Deductive (Myers et al., 2013). In research methodology, researchers apply both inductive and deductive methods to conduct inquiries and draw inferences. The choice between these methods depends on factors such as the research questions, availability data, and inclusive research design.

The inductive method in research jolts with specific annotations and data, aiming to identify patterns, themes, or relationships that lead to the development of broader theories or generalizations. This involves data collection through various empirical methods like observations, interviews, field surveys, or experiments. After gathering the data, thorough analysis is carried out to analyze common patterns or themes emerging from the observations. Based on these patterns, researchers progress theories or general principles that highligts the observed phenomena. Moreover, they may suggest broader conclusions and generalizations by inferring from their theories and analyzed data (Sileyew, 2019).

Inductive research is predominantly helpful in exploratory studies, where the focus is on gaining understanding about a new or relatively unexplored topic. Through inductive reasoning, researchers can generate hypotheses or theories that can be further tested and confirmed through deductive research methods.

Deductive research initiates by utilizing an established theory, hypothesis, or general premise as a starting point and then proceeds to examine it through specific observations or data (Hyde, 2000). This process typically follows these steps: First, researchers formulate a specific theory, hypothesis, or general premise based on existing knowledge or prior research. Second, they collect targeted data to test the validity of the theory or hypothesis. Third, the gathered data undergoes analysis to determine whether it supports or contradicts the initial theory or hypothesis (Azungah, 2018). Finally, based on the data analysis, researchers draw specific conclusions about the theory or hypothesis under examination.

Deductive research finds significant application in confirmatory studies, where the primary objective is to rigorously test existing theories or hypotheses (Gottfredson & Aguinis, 2017). Its aim is to provide empirical evidence that either supports or refutes the initial premises. It is crucial to acknowledge that inductive and deductive methods are not mutually exclusive, and researchers have the option to employ both approaches within the same study or research project. This combination of inductive and deductive reasoning is known as the "abductive" approach, where researchers move back and forth between data collection, analysis, theory development, and hypothesis testing (Woiceshyn & Daellenbach, 2018).

3.3 Research Design

The research process started with extensive exploration of research studies available in the context of AMTs adoption. In the beginning, adopting AMTs are justified as compared to trational method of manufacturing using AHP technique. Various parameters were analyzed including Improved flexibility (IF), Reduced production cost (RPC), Reduced inventory (RI), Reduced lead time (RLT), Delivery on time (DOT), Increased productivity (IP), and Innovative products (IPS). In the second phase, Industry readiness towards adopting AMTs was assessed using Graph Theory and Matrix Approach (GTMA) by analyzing the barriers. The identified barriers were categorized in to four categories namely Technical Information Barrier (TIB), Operational and strategic barriers (OSB), Financial and economic barriers (FEB), and Human Barriers (HB).

In the next phase of paper, fifteen Critical Success Factors (CSFs) of adopting AMTs were mapped with Performance Outcomes i.e. Cost Reduction, Agility in the processes, Sustainable Operations, Improvement in Product Quality, and Resilience. In the last phase of data analysis, case studies of organizations curious to adopt AMTs were analyzed using SAP-LAP framework.

3.4 GTMA for Analyzing Barriers of AMTs Adoption

The adoption of advanced manufacturing technologies (AMTs) presents numerous benefits, such as increased productivity and reduced production costs. However, several barriers hinder their successful implementation. Firstly, the high initial cost of acquiring and training for AMTs can be a challenge, especially for SMEs. Secondly, a lack of skilled workers familiar with these technologies can impede their adoption. Resistance to change from employees, fearing job displacement, is another obstacle. Additionally, integrating AMTs with existing manufacturing systems and ensuring data interoperability poses difficulties. Cybersecurity concerns, inadequate awareness of AMTs' potential benefits, and uncertain return on investment are also deterrents. Regulatory compliance, long payback periods, and reliance on reliable suppliers further complicate the adoption process. Overcoming these barriers requires careful planning, change management, upskilling the workforce, and aligning AMTs with the organization's business strategy. Therefore, it is highly essential to analyze the anticipated barriers and devise competitive strategies to tackle them.

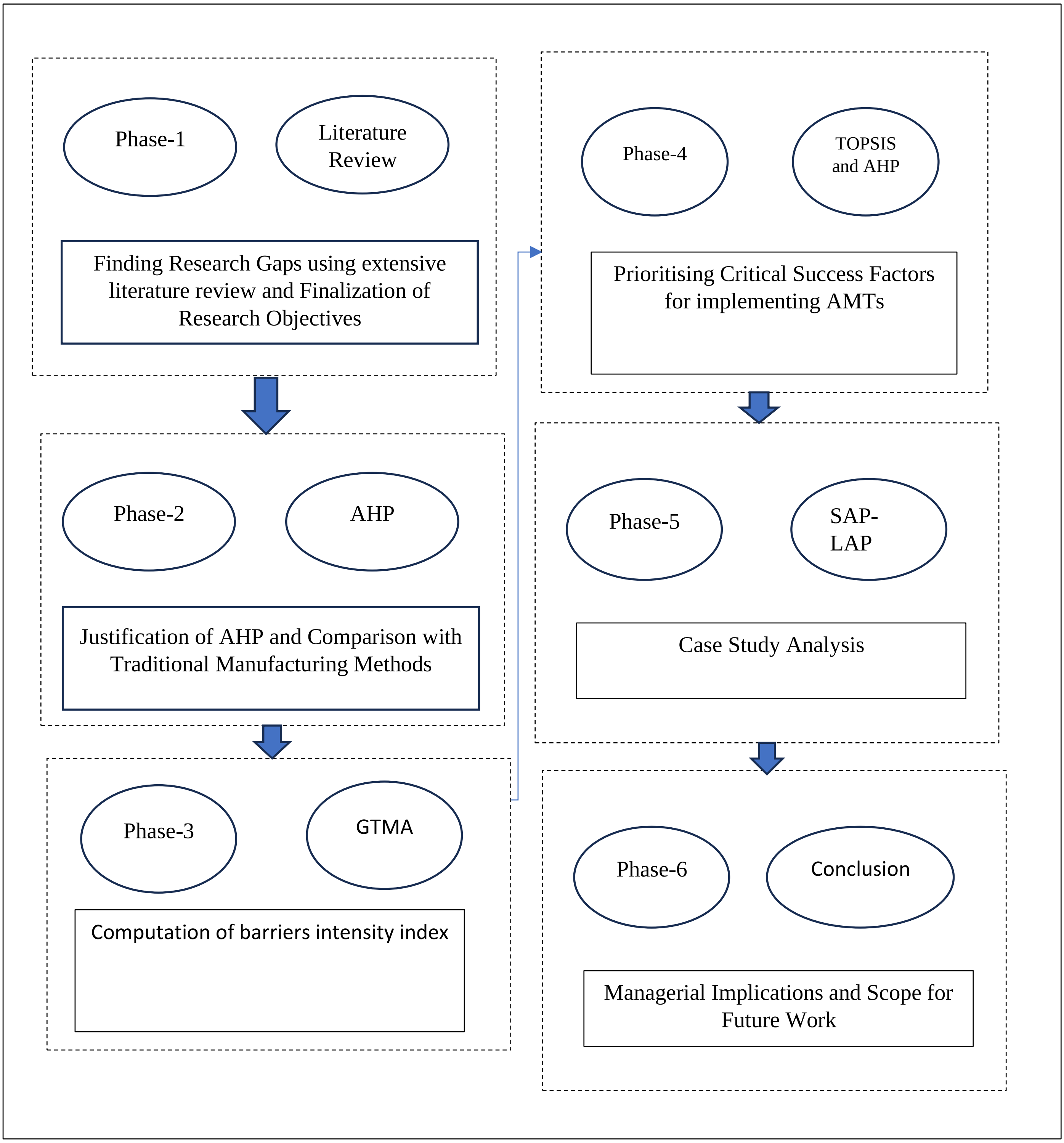

Figure 3.1: Research Methodology

GTMA is applied for evaluating the unfavourable impact of barriers in AMTs implementation. Generally, presentations of graph are carried out in the terms of figure which contains vertices and edges and imply point and line segment connecting its end vertices respectively. According to Zhang (2015), GTMA has attracted researchers as it has power to solve some complex problems. Many researchers have used it in the field of sustainability for analysing complex interactions among different factors (Luo et al., 2018, Eisenack and Petschel-Held, 2002). GTMA is also successfully applied in the area of quality (Grover et al., 2006), FMS (Raj et al. 2010); reverse logistics (Agrawal et al. 2016),manufacturing science (Rao and Gandhi, 2002), system modelling (Mohan et al., 2003), outsourcing decisions in reverse logistics(Agrawal et al., 2016),lean manufacturing (Anand and Kodali, 2010), supply chain uncertainty reduction (Faisal et al., 2006), supply chain analysis (Kaur et al., 2006), supply chain association (Anbanandam et al., 2011), mechatronic system (Kiran et al.. 2012); reliability (Sehgal et al., 2000); buyer–supplier relationships (Thakkar et al., 2008) and service provider study (Qureshi et al., 2009).

GTMA has following three significant parameters (Grover et al., 2006):

a) Visual analysis is carried out by digraph representation

b) The valuable expression of the computer processing is carried out by matrix.

c) Representing the impact of every variable by a distinct number or index for appropriate evaluation is carried out by Permanent expression.

The quantification of the impact of barriers of AMTs implementation is not carried out by previous studies. GTMA is most suitable tool for quantifying the impact of barriers (Anbanandam et al., 2011). In present research, GTMA methodology has been applied to analyse and quantify the impact of different AMTs barriers in a manufacturing organisation located at Faridabad, Haryana, India. On the basis of priority, the data are received about above said barriers from management of given organisation. Once the barriers are recognised and K_i (value of the factor expressed by node) are computed, the next step is to describe the relative priority of the ith factor over jth (r_{ij}) as per scale.

Table 3.1: Comparative significance of attributes (rij's), Muduli et al. 2013

Class definition	Comparative significance of attributes	
	r_{ij}	$r_{ji} = 10 - r_{ij}$
Two attributes are of equal importance	5	5
One attribute is slightly important	6	4
One attribute is very important over the other	7	3
One attribute is most important over the other	8	2
One attribute is extremely important over the other	9	1
One attribute is exceptionally important over the other	10	0

3.4.1 Steps of GTMA

GTMA consists of following important steps:

1. Recognise a number of different barriers which affects the implementation of AMTs.

2. Frame the identified barriers into different categories.

3. Major barriers categories are developed by the digraph based upon their interdependencies.

4. After developing the digraph among the barriers categories, subsystem digraph is developed for the distinct barriers category among the barriers as executed in step 3.

5. For every category of barriers, permanent matrix is developed.

6. The value of inheritance and interdependency in sub barriers matrix are put for every barrier category.

7. The value of permanent function is computed for every category of barriers.

8. The amount of inheritance and interdependency in barriers matrix are put to the system level. The scale (1-5) through proper interaction by scholars decides the quantitative number of interactions among barriers.

9. Calculate the amount of permanent function for the system. That amount of permanent is based on the existence of different barriers and their interdependencies will provide the index value which numerically distinguishes the restricting strength of different barriers in a specific organisation.

10.Calculation of Index value of above different categories of barriers.

Table 3.2: Barriers of AMTs

S.No	Barriers of AMTs	References	No. of Sub-Barriers
1	Technical Information barriers (TIB)	Gunningham and Sinclair (1997), Mitchell (2006)	4
2	Operational and strategic barriers (OSB)	Mittal et al. (2013), Mittal and Sangwan (2011), Shi et al.(2008)	4
3	Financial and Economic barriers (FEB)	Shi et al.(2008), Mittal and Sangwan (2011)	4
4	Human Barriers (HB)	Vickers et al. (1999), Haris et al.(2000), Kablan (2003).	4

3.5 AHP

AHP is popular MCDM technique initiated by Saaty (1980). Since its inception, it is used by various researchers in variety of applications like Supplier Selection (Awasthi et al., 2018), Equipment replacement (Oeltjenbruns et al., 1995),Green initiatives evaluation (Wang et al., 2012). It is a powerful decision-making tool which is usually applied to solve complicated problems, It make use of goals, criteria, sub-criteria and different solutions. These are evaluated to build a hierarchical structure. A pairwise comparisons among identified variables are done which are further used to compute the weights of decision variables. It can also be used to provide consistency which are found inconsistent prior while initiation of identified problem.

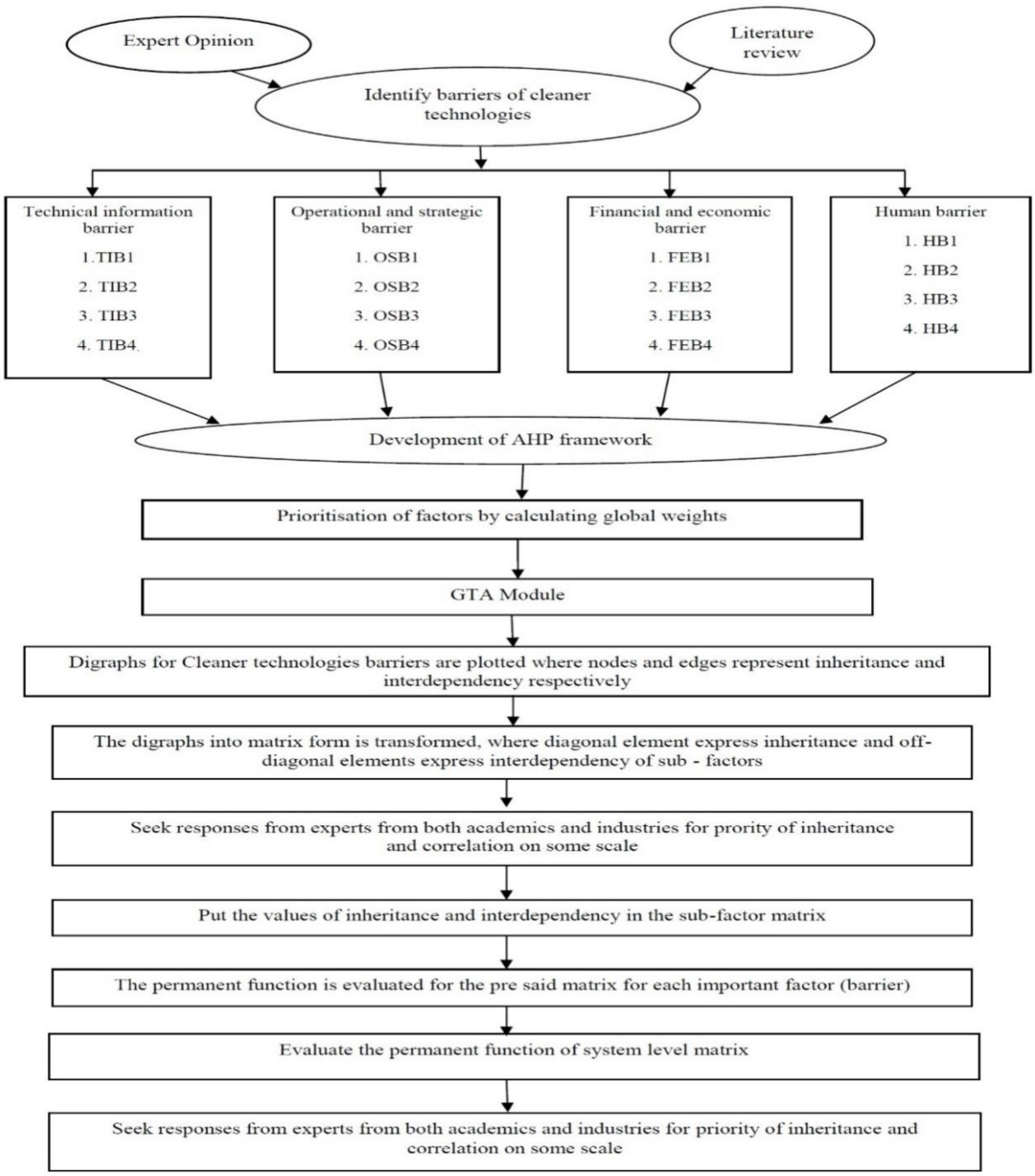

Figure 3.2: GTMA Framework

The key steps used in AHP are as follows:

1. Identify the research problem and widen the objectives of the problem.
2. List out the key criteria affecting the identified problem.
3. Develop ordered structure consisting of identified objective, its criteria, associated sub-criteria and feasible solutions.
4. Make Pairwise comparisons which is usually equals to p(p-1)/2, where p implies count of identified variables. Under the standard condition, the diagonal elements are supposed to be 1 and other cells are computed by taking reciprocals of previously held comparisons. The scale used is mentioned in Table 3.3.
5. Make computations to evaluate eigen values, consistency index CI, consistency ratio CR, and normalized values for every identified criteria or alternative.
6. The process continues until the value of CI and CR comes within the limits.

Table 3.3: Scale adopted for pair-wise computations (Saaty, 1994)

Relevance of Numbers	**Description**	**Definition**
1	Two attributes contributes likewise to the goal	Equally preferred
3	One attribute is somewhat favoured over the other	Moderately preferred
5	One attribute is intensely favoured over the other	Strongly preferred
7	One attribute is very intensely favoured over the other	Very strongly
9	One attribute is extreme strongly favoured over the other	Extremely preferred
2,4,6,8	In case, cooperation is required	Transitional numbers assigned in between the two consecutive judgements

Reciprocals of above mentioned values	A reasonable assumption	In case the activity ith as compared to jth activity have other mentioned intermediate numbers

Consistency Test

It is done to ensure that there is no human error or any form of biasness present while solving the particular problem. It is therefore imperative to evaluate the estimated vector and associated consistency level. Some of the acceptable CR values are given by Saaty (1994) as 0.05 for matrix of order 3, 0.08 for four order matrix and 0.1 for big matrices. The results are usually found to be satisfactory if CI falls within these limits.

- Perform normalization by dividing the each element in a matrix with corresponding summation of columns.
- The next step is to calculate the significance vector (SV). It is computed by taking the sum average of each row elements.
- The maximum eigen value is calculated as

$$\lambda_{\max} = \left(\sum_n b_{i1}\right)(SV)_{i1} + \left(\sum_n b_{i2}\right)(SV)_{i2} + \left(\sum_n b_{i3}\right)(SV)_{i3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots, n \in N \quad (1)$$

- After that $\lambda_{\max}$ and CI are computed.

  Where $CI = (\lambda_{\max} - M)/(M - 1)$ (2))

$where\,M\,reprents\,frequency\,of\ attributes$

- CR (Consistency Ratio)=CI/RCI

Where RCI=Random Consistency Index

Table 3.4: Values of RCI, (Saaty ,1980)

N	1	2	3	4	5	6	7	8
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

For consistency, CR need to be less than or equal to 10%, in that case computations are considered reliable (Table 3.4). On the other hand, subjective judgement needs revision if CR is greater than 10%.

3.6 Fuzzy TOPSIS Approach to prioritize CSFs of AMTs Adoption

CSFs for the successful adoption of AMTs include government policies, a skilled workforce with proper training, effective change management, strategic planning aligned with organizational goals, careful technology selection, clear understanding of strategic goals, regular performance monitoring, robust data security measures, reliable supplier relationships, a culture of continuous improvement, proactive risk management, and engaging all stakeholders in the adoption process. Addressing these factors enhances the chances of successful AMT implementation and helps organizations optimize the benefits of these technologies, gaining a competitive edge in the manufacturing industry.

3.7 SAP-LAP Framework

The case studies are analyzed using the SAP-LAP framework. Sushil (1997) describes as a flexible, innovative, creative, and qualitative tool for assessing case studies. The current study applies the SAP-LAP analysis framework to evaluate the challenges of adopting AMTs in the considered case industry. Data and information are collected in accordance with the SAP-LAP framework, offering decision-makers with a platform for critical thinking and problem-solving.

SAP, which implies for "Situation," "Actor," and "Process," is used to structure the analysis. "Situation" refers to the condition of the system being addressed, "Actor" represents the individuals or groups responsible for handling the specific situation, and "Process" indicates the transformation of existing methods of performing a task (Sushil, 1997). Following this, LAP analysis is conducted, involving "Learning," "Action," and "Performance."

3.8 Concluding Remarks

This chapter discussed the various techniques used for research data analysis. On the basis of research objective, research tool was selected and applied. The next chapter discussed the justification of AMTs over conventional methods, where AHP technique was applied to compute the weights of anticipated attributes and prioritize them.

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Chapter-4: Justification of advanced manufacturing technologies from Automotive sector

4.1 Introduction

Organizations are the lifeline of modern economies. In the present globalised scenario, the survival of organizations depends increasingly upon its manufacturing performance. According to Priyavrat (2011), Traditional Manufacturing is defined as the art of converting raw materials into finished products by using manual or mechanized transformational techniques. The purpose of such activities is to add value to achieve targeted objectives, which do not preclude society's overall interest. To meet the market globally, organisations must adopt AMTs in their production system so that they can fulfil the customer demands, deliver their product on time and face challenges in the market. Many studies have intensified the potential strategic benefits of flexibility, responsiveness, improved productivity, and improved quality through purposeful investment in AMTs (Zammuto and O'Connor, 1992). Major problems in manufacturing could be solved by increasing use of AMTs. The benefits of AMTs are increasing productivity, improving flexibility, producing higher quality products, reducing production costs (Beaumont and Schroder, 1997; Rischel and Burns, 1997; Small, 1998).

Organisations can improve their performance using advanced manufacturing technologies in their production system in terms of low cost, flexibility, lead time reduction etc. According to Priyavrat (2011), organisation which uses AMTs in their production system will produce products which have high level of product design, reliable products, technologically complicated & innovative products.

Influenced by this new competitive scenery, Brown (2000) states that if organizations want to remain in business, there is no alternate between whether to invest in technology or not. It can only make decisions about the type and extend of process technological investment. The adoption of the automated systems has been one of the available alternatives for companies to compete within this new reality (Boyle, 2006; Zhang et al., 2006). As technology is important for the development of a country, the management of such important resources, both at enterprise level and national level, are vital. All these call for an effectual utilization of new advanced technologies for the growth of the enterprise and for greater competitiveness (Isa and Foong, 2005). AMTs play an important role in quality and flexibility improvements in organizations. According to Mathew (2013), the importance of flexibility and efficiency has increased in the manufacturing sector within the last decade.

According to Bhaskar (2013), organizations in Indian Auto – Component Industry covers a wide spectrum of industries, that is, rubber, iron and alloy steel, plastic, oils and grease, fabrication tools, safety gadgets, air conditioning, radiators, mould making, battery industry, electrical fittings, interior furnishings, music system, sheet metal fabrication, lamps and bulbs, spring manufacturers – it covers basic industry and white goods. This sector has a bearing on Power consumption and skilled labour availability and has a considerable contribution in GDP (Manufacturing) – for FY 12 GDP at factor cost is 2.1%. The growth of Indian Auto Component Industry in the little over first decade of the 21st Century is phenomenal. The industry transformed gradually in stages from serving just Indian market – majority to replacement market - to global OEMs and replacement market.

Globalization has brought increased stress on the organisations, who have to repeatedly reduce prices against a backdrop of improving quality and services. For keeping in race of global competition, it is essential that the firms increase performance standards in many dimensions such as quality, cost, productivity and smooth flowing operations (Hitt et al, 2001). With globalization, the organisations are under increasing pressure to adopt advanced manufacturing technologies (AMTs) to be competitive or simply to survive (Mathew, 2013). Key conditions like capacity of a firm to maintain reliable, continuously improving business and manufacturing process meet for ensuring its competitiveness in long run (Lagace and Bourgault, 2003). The growth and the competitiveness in globalised market can be sustained by organizations by adopting advanced manufacturing technologies (Singh et al., 2006). In the present situation of globalization, organizations should have the ability to innovate quickly and produce an acceptable product and service to capture upcoming business opportunity (Dangayach and Deshmukh, 2001).

According to Dangayach and Deshmukh (2005), AMTs appeared to represent a perfect marriage between technological potential and the manufacturing challenges. Advanced Manufacturing Technologies represents a wide variety of modern computer-based or numerical control-based systems devoted to the improvement of manufacturing operations. An AMTS consists of varying combinations of hardware and software components, with some form of computerised or numerical control. Some AMTs such as Computer Aided Design and Computer Aided Process Planning are software based with computerised control, while Numerical Controlled (NC) machining centres consist of predominantly hardware components controlled by numerical commands' (SMALL, 1993). According to Zammuto and O'Connor (1995), AMTs refer to a group of technologies that include computer-aided design (CAD) and engineering systems, materials resource planning systems, automated materials handling systems, robotics, computer-controlled machines, flexible manufacturing systems, and computer-integrated manufacturing systems. Introduction of new products can occur more frequently through use of computer-aided design and manufacturing (CAD/CAM), since the design lead times may be shortened. Flexible manufacturing systems (FMS) and automated materials handling systems reduce set-up times and other interruptions so that products flow more smoothly and faster through the plant (Jonsson, 2000). Organizations in India are constrained with different kind of resources. Due to it, most of organizations are still following traditional manufacturing practices and outdated technologies. To compete in global markets, Organizations need to implement advanced manufacturing technologies (AMTs) and standard operating practices.

Therefore, this study will try to address following research questions.

RQ1: Why do organisations need to implement AMTs?

RQ2: What are the major benefits for implementing AMTs in organizations?

RQ3: Is use of AMTs in organisations justified?

4.2 Importance of Advanced Manufacturing Technologies (AMTs)

What is the value-added by advanced manufacturing versus traditional manufacturing? While traditional manufacturing plays a compulsory role in producing commercially necessary products, it does not require highly technical and specialized labour or innovation (ACMA, 2011). As such, it does not generate enough to buoy a country's economy in the long term (NASSCOM, 2007; Singh et al., 2007). Moving beyond simple manufacturing into advanced manufacturing further pushes an economy into creating higher value-added products, a key element to sustainable economic growth, job creation, and the development of new markets (Necipoğlu.I, 2015).

Advanced Manufacturing Technologies (AMTs) expresses a broad range of modern manufacturing systems, mainly computer based which are dedicated to the improvement of manufacturing operations. Advanced manufacturing technologies reduce the amount of rework and waste and enhance quality and reliability for the customer. The domain of competition is quite large because manufacturers compete at inter-manufacturing and intra-firm levels, producing reliable and flexible products. Customer wants a product which functions most reliably, while addressing socio-techno-environmental attributes (Priyavrat, 2011). According to (Rosen and Lipson, 2011) Instead of competing on labour costs, if advanced manufacturing becomes a mainstream manufacturing process, firms and countries will compete on creativity and design. To compete, manufacturers have invested substantial resources in advanced manufacturing technologies (AMTs), improvement programs such as kaizen and total quality management (TQM), and process improvements such as just-in-time (JIT). These investments have not always provided the same payoff or even the expected payoff for manufacturers (Kennedy and Hyland, 2003).

AMTs serves to enable high-performance manufacturing in companies to meet increasing expectations. Manufacturing companies struggle to lower cost, improve quality, increase throughput, and at the same time, be flexible in their production (Hynek and Janacek, 2013). Unfortunately, not all AMTs perform as expected. Some ended to be ‘satisfactory’ without producing the full benefits and some ended up a total failure. Various empirical studies have proven the benefits of AMTs when it is implemented correctly (Singh and Khamba, 2010).

According to Singh et al. (2007), the major drivers for implementing AMTs are top management commitment and sound financial condition. Organizational performance such as product cost, fast delivery, lead time and product quality will have improved by effective implementation of AMTs. The managerial aspects such as organization culture, employee training, integration of departments, vendor developments, strategy development and customer involvement should not be ignored. The key roles of AMTs are adoption of top management support, enthusiasm, motivation and encouragement (Al-Qirim, 2007; Ramdani et al. 2009). Studies reveal that manufacturing companies which were successful in AMTs implementation had, opted for a more flexibility-oriented organizational culture that might have simplified the AMTs implementation through creating an atmosphere of encouragement and trust (Yusuff et al. 2008).

4 2.1 Why Organizations need AMTs?

AMTs provides major benefits in areas that would enable organizations to sustain quality, organizational, operational, and financial performances. AMTs are source of competitive benefits, such as improved quality, greater flexibility, and cost reduction. Industries must carefully manage the implementation of these technologies to achieve those benefits (Dangyanch and Deshmukh, 2005). *To be able to survive and rise, industries must adopt Advanced manufacturing technologies and innovative management practices in their system.*

In order to lower their operating costs, increase productivity and quality, and respond to the increased requirements of their customers and other business partners, a huge number of manufacturing industries have scanned the technological environment and made required investments in adopting advanced manufacturing technologies such as computer-aided design and manufacturing (CAD/CAM) and flexible manufacturing systems (FMS) (Mechling et al., 1995). A major area of investment in Indian auto component sector is emerged automation of process for competing in global market in present scenario (Singh et al., 2007). A greater number of growth options to enter new markets and to create new products than firm relying on traditional manufacturing and generic strategies are given by adoption of AMTs.

According to Dawal et al. (2015), AMTs plays a major role in improving flexibility, timely delivery and quality of industries. To gain profits and competitive advantage firms have implemented and introduced AMTs. It aims at manufacturing high quality products at low cost within the shortest delivery time. It is accepted that operations/manufacturing strategies of a company consist of four significant competitive priorities: quality, cost reduction, dependability/delivery and flexibility (Dangayach and Deshmukh, 2003). Advanced IT tools such as ERP/SCM software can help industries to increase productivity, improve inventory controls, increase sales through closer relationships and faster delivery times (NMCC and NASSCOM, 2010). AMTs can enhance productivity in several ways. They dramatically raise flexibility by making it feasible for manufacturers in some industries to offer customers the option to "have it your way" (Sirkin et al. 2015). Chen and Small (1996) have observed that the strategic role of AMTs has been related to improving the firm's ability to cope with environmental uncertainty, but it has also been viewed as an important factor for the overall improvement of industrial performance.

4.2.2 Classification of AMTs

There are many technologies used in manufacturing sector although level of their application may change from firm to firm.

According to Saliba et al. (2017), AMTs have been classified into

(i) Stand-alone systems (e.g., computer-aided design (CAD) and computer-aided engineering (CAE) systems)

(ii) Intermediate systems (e.g., computer numerically controlled (CNC) machines, automated material handling systems (AMHS), automated storage and retrieval systems (AS/RS), and automated inspection systems (AIS)

(iii) Integrated systems, sub-divided into integrated process technologies (e.g., computer-integrated manufacturing (CIM) and flexible manufacturing systems (FMS) and integrated/logistic technologies (e.g., just-in-time production (JIT) and manufacturing resource planning (MRP II).

According to Dangayach and Deshmukh (2005), AMTs are classified into Direct AMTS, Indirect AMTS, and Administrative AMTS. It must be mentioned that this set is by no means an exhaustive set of activities. However, it captures the essence of improvement activities as practiced by Indian companies. Hardware base technologies are termed as Direct AMTs. Software-based technologies used for product design and scheduling are termed as Indirect AMTS, however, Administrative AMTs are used for integration and simplification of business processes:

- Direct AMTs- Technology used on the factory floor to cut, join, reshape, transport, store or modify materials, e.g. CNC, DNC, robotics, FMS, AS/RS, AMHS, AGV, RP, etc.

- Indirect AMTs- Technology used to design products and schedule production, e.g., CAD, MRP, SPC, BC, MRP II, etc.
- Administrative AMTs- Technology used to give administrative support to the factory and integrate its operations with the rest of the organization, e.g., ERP, ABC, OA, etc

Based on literature review seven important benefits of using AMTs compared to traditional manufacturing are recognised. These are improved flexibility, reduced production cost, reduced lead time, delivery on time, increased productivity, innovative products, and reduced inventory (Table 4.1). In this study comparison is done between AMTs and traditional manufacturing. Justification of AMTs will be based on these benefits.

Table 4. 1: Benefits of AMTs Implementation

Abbreviation	**Benefits**	**References**
IF	Improved flexibility	Zammuto and O'Connor (1992), Dangayach and Deshmukh (2003), Dangyanch and Deshmukh (2005), Khazanchi et al.(2007), Priyavrat (2011), Mathew (2013),Sirkin et al.(2015), Dawal et al. (2015)
RPC	Reduced production cost	Dangayach and Deshmukh (2003), Khazanchi et al. (2007), Beaumont et al.(1997), Hitt et al. (2001), Saliba et al. (2017)
RI	Reduced inventory	Khazanchi et al. (2007), Macher and Mowery (2008).
RLT	Reduced lead time	Dangayach and Deshmukh (2003), singh et al. (2007), Sanders(2011), Saliba et al. (2017)
DOT	Delivery on time	Dangayach et al. (2003), Singh et al. (2007), Priyavrat (2011), Khazanchi et al. (2007), Dawal et al. (2015), Chougale and Pethkar (2016)

IP	Increased productivity	Sirkin et al.(2015), Hitt et al.(2001), Khazanchi et al. (2007), NMCC and NASSCOM (2010)
IPS	Innovative products	Priyavrat (2011), Raymond (2005), Zhou et al. (2009), Dangayach and Deshmukh (2001).

4.3 Research methodology

Justification of AMTs is based on multiple criteria as discussed in Literature review. Therefore, for this study Multi Criterion Decision Making tool i.e. AHP is used. The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach and was introduced by Saaty (1980 and 1994). The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain. The AHP is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub criteria, and alternatives. The pertinent data are derived by using a set of pair wise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. If the comparisons are not perfectly consistent, then it provides a mechanism for improving consistency. Some of the industrial engineering applications of the AHP include its use in integrated manufacturing in the assessment of technology investment decisions in flexible manufacturing systems, layout design and in other engineering problems. It also provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances. The scale ranges from1 to 9 for least valued i.e. 1 for equal and to 9 for absolutely more important. Some key and basic steps involved in this methodology are:

1. State the problem and broaden the objectives of the problem.
2. Identify the criteria that influence the behaviour.

3. Structure the problem in a hierarchy of different levels constituting goal, criteria, sub - criteria and alternatives.

4. Compare each element in the corresponding level and calibrate them on the numerical scale. This requires n (n-1)/2 comparisons, where n is the number of elements with the considerations that diagonal elements are equal or 1 and the other elements will simply be the reciprocals of the earlier comparisons.

5. Perform calculations to find the maximum Eigen value, consistency index CI, consistency ratio CR, and normalized values for each criteria / alternative.

6. If the maximum Eigen value, CI, and CR are satisfactory then decision is taken based on the normalized values; else the procedure is repeated till these values lie in a desired range. AHP helps to incorporate a group consensus. Generally, this consists of a questionnaire for comparison of each element and geometric mean to arrive at a final solution. The AHP can be very useful in involving several decision-makers with different conflicting objectives to arrive at a consensus decision.

Mainly this study has gone through three phases.

1. Formulating the problem and structuring a hierarchy AHP model.

2. Collecting data from experts.

3. Determining the normalised priority weights of individual factor and sub factor

Phase 1: structuring a hierarchy model

The aim of our study is to justify the advanced manufacturing technology over traditional manufacturing. This aim is placed on the first level of the hierarchy. Seven major benefits, namely improvement in flexibility, reduced production cost, reduced inventory, reduced lead time, delivery on time, increased productivity and innovative products are determined to achieve this aim from the second level of hierarchy. The major benefits of using advanced manufacturing technology in second level of hierarchy can be evaluated using the basic AHP approach of pair wise comparison of factors in each level with respect to every parent factor situated one level above. The third and last level consists of two alternatives, i.e., advanced manufacturing and Traditional manufacturing. AHP model is shown in Figure 4.1.

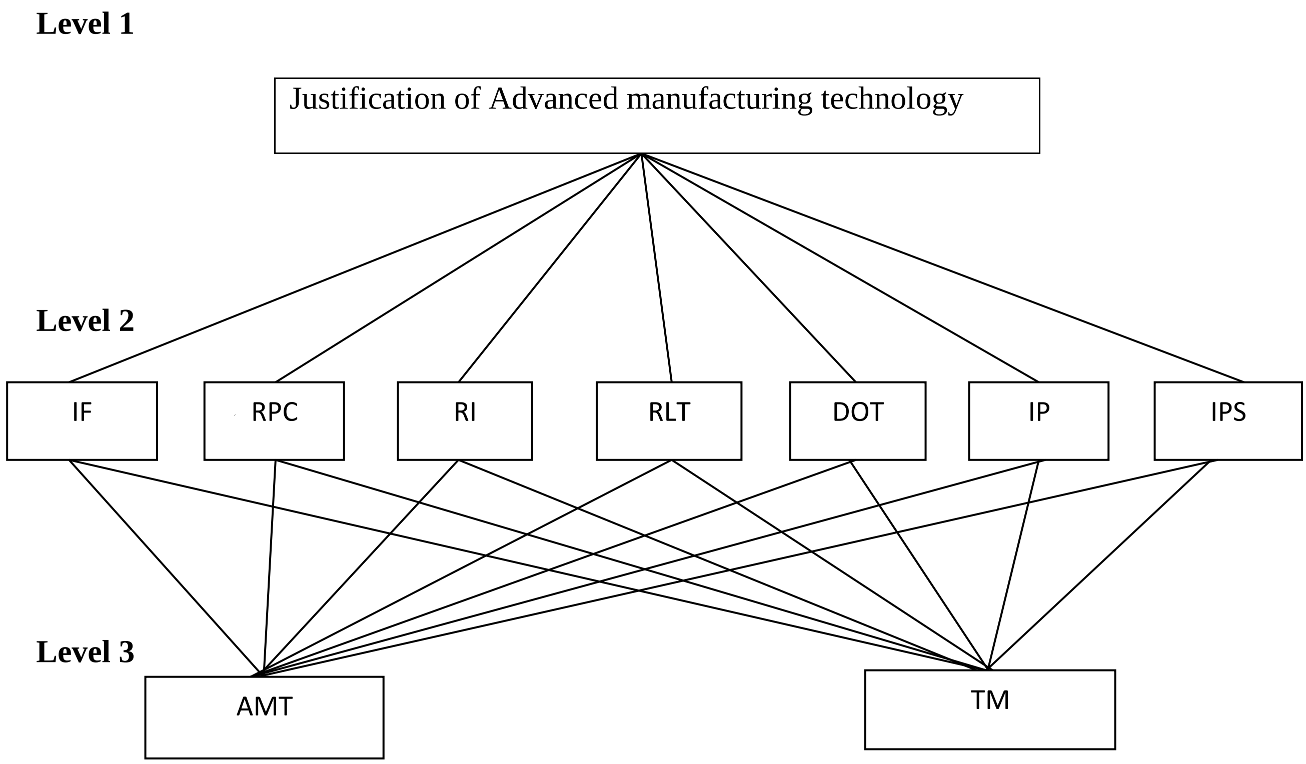

Figure 4.1: Schematic of AHP model

Phase2: Data collection from experts

The next phase is the measurement and collection of data from the experts. It consists of a team of experts who allocate pair-wise comparison to the main factors used in the AHP hierarchy. The nine-point scale (Table 4.2) was used to allocate relative scores to pair wise comparisons among the important factors. The experts were asked to assign a score to each comparison using the nine-point scale. This method continued till all levels of the hierarchy and finally a series of judgement matrices for the important factors were obtained. Team consisted of seven experts, out of these seven experts; four were from manufacturing industry, such as auto component industry and three from academia. Each one of them has more than fifteen years of experience mainly in auto component sector. A questionnaire consisting of all important factors of the two levels of AHP model is designed and is used to collect the pair wise comparison judgement from all experts. The majority was given importance if consensus was not reached. AHP approach was applied by Bayazit (2005) in decision making for flexible manufacturing systems by having a team of six managers from different departments. Zaim et al. (2012) also had a team of five decision makers while selecting maintenance strategy. Singh (2012) applied AHP for justification of coordinated supply chain in industries. Singh (2013) applied (AHP) to prioritize the factors for a coordinated supply chain. Vinodh et al. (2012) applied AHP-based lean concept selection in a manufacturing organisation.

Table 4.2: Scale for pair wise comparisons (Saaty, 1994)

Intensity of numbers	Explanation	Definition
1	Two activities contribute equally to the objective	Equal preferred
3	Experience and judgement slightly favour one activity over another	Moderately preferred
5	Experience and judgement strongly favour one activity over another	Strongly preferred
7	An activity is favoured very strongly over another; its dominance demonstrated in practice	Very strongly
9	The evidence favouring one activity over another is of the highest possible order of affirmation	Extremely preferred
2,4,6,8	When compromise is needed	Intermediate values between the two adjacent judgements

Reciprocals of above non zero	A reasonable assumption	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i

4.4 Evaluating priority

Based on expert's opinion to evaluate the relative importance of seven major factors, the pair wise comparison judgement matrices were formed in the data collection phase. For determining the priority, the procedure is as follows-

i) Compare each element in the corresponding level and calibrate them on the numerical scale. This requires n (n-1)/2 comparisons, where n is the number of elements with the considerations that diagonal elements are equal or 1 and the other elements will simply be the reciprocals of the earlier comparisons.

ii). Perform calculations to find the maximum Eigen value, consistency index CI, consistency ratio CR, and normalized values for each criteria / alternative.

iii) If the maximum Eigen value, CI, and CR are satisfactory then decision is taken based on the normalized values; else the procedure is repeated till these values lie in a desired range. AHP helps to incorporate a group consensus. Generally, this consists of a questionnaire for comparison of each element and geometric mean to arrive at a final solution.

Due to human error and possibility of biased ness, it is often inconsistent answering the question. Therefore, important task of AHP is to calculate the consistency level of the estimated vector. Consistency Ratio (CR) is used to measure the consistency in the pair wise comparison. According to Saaty, (1994), acceptable CR value for different matrices size is as 0.05 for a 3-by-3 matrix, 0.08 for a 4-by-4 matrix and 0.1 for large matrices. If consistency level falls into the acceptable range, the results are valid.

Having compared all pair wise attributes and entered data in the form of matrix, the consistency is determined using the eigen values. For calculating the eigen values following procedures are adopted:

- Normalise the column of numbers by dividing each entry by the sum of all entries of respective column.
- After normalizing the column, priority vector (PV) is calculated. For doing so, the average of sum of each row of normalized value provides priority vector (PV).
- The sum of product of each priority vector (PV) of row to sum of all entries to corresponding columns provides maximum eigen value.

$$\lambda_{max} = (\sum_{n} a_{i1})(PV)_{i1} + (\sum_{n} a_{i2})(PV)_{i2} + (\sum_{n} a_{i3})(PV)_{i3} + \ldots\ldots\ldots\ldots \quad n€N$$

- Knowing the λ_{max}, CI (Consistency Index) is calculated.

  CI= (λmax- N) / (N-1) Where N is the number of elements.

- CR (Consistency Ratio) = CI / RCI

Where RCI= Random Consistency Index

Table 4.3: Average random index values, (Saaty, 1980)

N	1	2	3	4	5	6	7	8
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41

If the value of CR is less than or equal to 10%, judgements are considered consistent. If the value of CR is greater than 10%, then there is need to revise the subjective judgement.

After computing the priority for each pair-wise comparison, judgement matrices of the AHP hierarchy, the next phase is to synthesise the conclusion for justification of factors for advanced manufacturing technology. Advanced manufacturing technology global weight can be evaluated by multiplication of corresponding factors of level 2 priority value to advanced manufacturing technology of corresponding factors of priority value similarly for traditional manufacturing technology global weight can be calculated.

4.5 Results and Discussions

For this study a reputed company, M/S A.B.C private limited, had been selected which was established in 1970 at the heart of industrial area of Faridabad (Haryana). It manufactures sheet metal pressed special deep drawn which are used as original equipment by leading automobile manufacturers of India. Out of them following are important vendors: Mahindra &Mahindra, Tata Motors, Kirloskar, Maruti, Johndeere, New Holland, Ford Fiat, Mahindra Swaraj and General Motors.

Company manufacturers following products: Air cleaner mounting bracket assembly,

Bracket spare wheel mounting, Brackets, Fire wall fuel tank mounting, Bracket front engine assembly. Table 4.4 represents the list of awards provided to ABC Ltd by different companies. Table 4.5 represents the status of technologies implemented in ABC Ltd.

Table 4.4: List of awards provided to ABC Ltd by different companies

Company Name	Award type
Maruti	Quality and Delivery Improvement
Johndeere	Appreciation Award
Tata Motors	Excellence in delivery award
Tata Motors	Enduring Relationship award
New Holland	Best Supplier award
Mahindra Swaraj	Best supply chain management award

Table 4.5: Status of technologies implementation in ABC ltd

Technology Applied	Status
1. CAD (Computer Aided Design)	Implemented in Design (Technical and Engineering Drawing
2. CAM (Computer Aided Manufacturing	Implemented in use of a computer to assist in all operations of a manufacturing plant, including planning, management, transportation, and storage
3.MRP (Material Requirement Planning)	In process of implementing in organizing inventory and production planning
4. Robotics	Implemented in welding but in process of implementing in material handling and in assembly.
5.Information and Communication Technologies	Unaware of using this technology but can be used in process, package, distribute, retrieve, store and transform information.
6.ERP (Enterprise Resource Planning)	Implemented in inventory management and now in process of implementing in manufacturing and product planning.

On the behalf of case study of the company model of AHP has been developed and is used for justification of advanced manufacturing technology in Organizations. Pair-wise comparison judgement matrices are formed after developing model of AHP for determining the priority value based on experts' opinion from the company. Table 4.6 shows pair wise comparison matrix for all seven important benefits criteria of AMTs. For checking the degree of consistency in the pair-wise comparison CR is calculated.

Results are shown in Table 4.6. From Table 4.6, it is noticed that for all seven factors AMTs has more PV in comparison to Traditional manufacturing. Table 4.7 shows local priority of attributes for alternatives. Table 4.8 shows the global weights of the seven major benefits for advanced manufacturing technology.

Global weights have been calculated by following method, Singh (2012):

Individual weight of the main factor = P.V. value from the respective table

Individual weight of the sub factor = P.V. value from the respective table

Global weight of main factor = individual weight of that main factor

Similarly, global priority for other strategic factors and sub factors can be calculated:

Global Wt. of Advanced manufacturing technology (AMTS) = Level 2 Wt. × CSC Wt.

Global Wt. of Traditional manufacturing (TM) = Level 2 Wt. × NCSC Wt.

Total global priority = sum of the global priority of respective columns.

Out of important benefits of using AMTs, the highest global priority value is productivity improvement (0.290). Increase in productivity leads to increase in profits, meeting customer demands and can increase the level of competition in the market. Second highest global priority value is Delivery on time (0.157). In this competitive environment a very important factor is the delivery of product. Organizations should be technically and financially strong to meet the target of on time delivery. If they are in habit of using AMTs, they can deliver the products on time. Also, e-commerce provides many opportunities for Organizations. E-commerce policy of delivery on time and customer service is important factor for their growth. Delivery on time is an important order winning criteria for Organizations. Time is an important factor as it reflects the potential of a manufacturing system. Third highest global priority value is reduction in production cost (0.125). Fourth highest global priority value is innovative products (0.084). Innovative products lead to the satisfaction of the existing requirements of a customer. It can also leads to the profit growth of organizations as the product is unique to what the competition offers. More than 90% of the world's 100 most companies which are innovative have accomplished positive sales growth due to innovation.

Fifth highest global priority is reduction in lead time (0.081). More lead time is one of the major problem of organizations. Reduction in lead time has an important effect on cost. A true competitive advantage is delivering faster. Less inventory and better logistics lead to reduction in lead time. Less inventory lead time equals to more gains. Next benefit of using AMTs is inventory reduction (0.036). Higher inventory adds to no value. More inventories mean more time that your inventory is sitting in your warehouse or storeroom which will lead to blockage of money. Major problem of organizations is finance. Fewer inventories lead to less waste. Next benefit of using AMTs is improved flexibility. Low labour cost is an important benefit of using AMTs. It can produce large number of variety of products at a time. Design of production can easily be changed by using AMTs.

Table 4.10 shows global desirability index of AMTs and Traditional manufacturing. Global desirability index of AMTs is 0.800 and of traditional manufacturing is 0.200. Global desirability index of AMTs is much higher than that of traditional manufacturing.

Table 4.6:Level 2 -pair wise comparison matrix

	IF	**RPC**	**RI**	**RLT**	**DOT**	**IP**	**IPS**	**P.V**
IF	1	1/5	½	1/3	1/6	1/7	¼	0.032
RPC	5	1	3	2	½	1/3	2	0.146
RI	2	1/3	1	¼	1/5	1/6	1/3	0.045
RLT	3	½	4	1	½	1/5	½	0.093
DOT	6	2	5	2	1	1/3	3	0.210
IP	7	3	6	5	3	1	3	0.362
IPS	4	½	3	2	1/3	1/3	1	0.112

Table 4.7:Pair wise judgement matrices

Analysis based on Improvement in flexibility			
	AMTs	TM	PV
AMTs	1	5	0.833
TM	1/5	1	0.167
Analysis based on Reduction in production cost			
	AMTs	TM	PV
AMTs	1	6	0.857
TM	1/6	1	0.143
Analysis based on Inventory reduction			
	AMTs	TM	PV
AMTs	1	4	0.8
TM	¼	1	0.2
Analysis based on Lead time reduction			
	AMTs	TM	PV
AMTs	1	7	0.875
TM	1/7	1	0.125
Analysis based on Delivery on Time			
	AMTs	TM	PV
AMTs	1	3	0.75
TM	1/3	1	0.25
Analysis based on productivity improvement			
	AMTs	TM	PV
AMTs	1	4	0.8
TM	¼	1	0.2
Analysis based on Innovative products			
	AMTs	TM	PV
AMTs	1	3	0.75
TM	1/3	1	0.25

Table 4.8:Weight of attributes for alternatives

Sr.no.	Attributes	Level 2 (P.V)	AMTS (P.V)	TM (P.V)
1	IF	0.032	0.833	0.167
2	RPC	0.146	0.857	0.143
3	RI	0.045	0.800	0.200
4	RLT	0.093	0.875	0.125
5	DOT	0.210	0.750	0.250
6	IP	0.362	0.800	0.200
7	IPS	0.112	0.750	0.250

Table 4.9:Desirability index of alternative global priority

Sr.no.	Attributes	AMTS (P.V)	TM (P.V)
1	IF	0.027	0.005
2	RPC	0.125	0.021
3	RI	0.036	0.009
4	RLT	0.081	0.012
5	DOT	0.157	0.053
6	IP	0.290	0.072
7	IPS	0.084	0.028
Total global(P.V)		**0.800**	**0.200**

Table 4.10:Global desirability index of alternatives

1	Global desirability index of AMTS	0.800
2	Global desirability index of TM	0.200

4.6 Concluding Remarks

Organizations are facing highly competitive environment aftermarket globalisation. To survive in such a competitive market, they need to implement best operations practices and suitable AMTs as per available resources. This study has tried to justify implementation of AMTs in organizations based on different benefits over traditional manufacturing. AHP approach is used to justify the application of AMTs in organizations. It is observed that AMTs enabled production systems have more desirability index as compared to traditional manufacturing. Seven important benefits of using AMTs have been identified in this study. Among seven benefits, increased productivity has got highest desirability index followed by delivery on time, reduced in production cost, innovative products, reduced lead time, reduced inventory, and improved flexibility. To improve performance in terms of increasing productivity, delivery on time, reduction in inventory, organizations should be motivated to use AMTs in their production process.

Although findings will be highly useful for organizations, but these cannot be generalised because of smaller size of respondents' team and based on a case study. Many other benefits related to sustainability in operations could be also considered in the future study for implementing AMTs in the industries. There are also chances of biasing while making pair wise comparisons to different factors. Therefore, due care should be taken while deciding relative score to different factors. These findings may be further validated with empirical studies. The next chapter talks about prioritizing the barriers using GTMA approach.

Chapter-5: Prioritization and evaluation of barriers intensity index for advanced manufacturing technologies implementation

5.1 Introduction

The implementation of advanced manufacturing technologies (AMTs) has a significant impact on enhancing manufacturing excellence (Abd Rahman & Bennett, 2009). The use of automation and robotics in advanced manufacturing technologies can increase productivity by reducing manual labor, increasing production speed, and reducing errors. Furthermore, the integration of computer-aided design (CAD) and computer-aided manufacturing (CAM) systems in advanced manufacturing technologies can enhance product quality by enabling precise design and production processes (Abdul-Hamid et al., 2020). In the current scenario, the advent of industrialization has led to a more comfortable and easier lifestyle for human beings (Alkaraan et al., 2022). Hartmann and Moeller (2014) have observed that the damage to sales caused by unsustainable practices is more significant than the cost incurred to ensure a sustainable environment, as seen in the case of Nestle. To address these challenges, it is crucial to measure the influence of various barriers in the implementation of advanced manufacturing technologies (AMTs) so that managers can formulate strategies to reduce or minimize their adverse impacts. Based on literature review and expert opinions, four categories of barriers have been identified, including technical information barriers, operational and strategic barriers, financial and economic barriers, and human barriers. In this study, a hybrid approach comprising of the Analytic Hierarchy Process (AHP) and graph theoretic approach (GTA) has been used. AHP has been used to prioritize different categories of barriers, while GTA has been applied to find the barriers intensity index. The study found that finance and economic barriers emerged as the major hurdle in implementing advanced manufacturing technologies (AMTs). The proposed framework will help organizations in quantifying barriers in implementing AMTs in different processes and developing effective strategies for sustainable production.According to literature, the implementation of advanced manufacturing technologies (AMTs) can provide organizations with sustainable competitive advantage.

Additionally, Song and Wang (2018) observed that the application of AMTs can help countries in creating sustainable competitive advantage by developing both the economy and the environment. They found that AMTs are reconfigurable and recyclable and do not harm societies and nature. This has led to an increased focus on the implementation of AMTs to create a sustainable and competitive manufacturing sector. Moreover, Song et al. (2012) emphasized that for sustainable growth, organizations must change their traditional production systems to those that are more environmentally friendly.

Advanced manufacturing technologies (AMTs) have played a crucial role in the evolution of the industrial revolution (Baas, 2007). This has led to improved product quality, reduced costs, and increased competitiveness. AMTs have also been instrumental in driving the fourth industrial revolution, or Industry 4.0, which integrates advanced technologies such as artificial intelligence, the Internet of Things, and big data into the manufacturing sector. This integration has resulted in increased automation, better decision-making, and more personalized production. The use of AMTs has enabled manufacturers to achieve greater precision, speed, and accuracy in their production processes. This has allowed them to respond quickly to changes in demand, increasing their agility and competitiveness (Khalili et al., 2014). In conclusion, the role of advanced manufacturing technologies in the industrial revolution has been paramount(Yongqiang, 1995). They have driven innovation, increased efficiency, and enabled manufacturers to achieve new levels of productivity and competitiveness. AMTs have opened up new opportunities for growth and have been instrumental in shaping the future of the manufacturing industry (Hilson, 2000).

In developing countries, organisations face severe challenges in implementing AMTs to ensure sustainable production. These are not able to adopt strategic approach in this direction due to lack of awareness and other financial constraints. Therefore, organisations need to be sensitised for application of AMTs to make their production system sustainable and globally competitive. Therefore, objectives of present study are as follows:

- To identify the different barriers in application of AMTs
- To prioritise different categories of barriers from strategic point of view.
- To develop a mathematical index for assessing the intensity of barriers for implementing AMTs from benchmarking perspective.

5.2 Identification of Barriers

Weber (1997) has observed that implementing AMTs are not a simple task. It is severely obstructed by a number of different types of barriers. Hilson (2000) has analysed different types of barriers in application of AMTs. Foxon et al. (2005) have also suggested various barriers disturbing the AMTs application within UK organisations. According to Hafez (1994), poor monitoring, top management commitment, environmental legislation and enforcement, lack of incentives, lack of adequate training are the hurdles in the implementation of AMTs.

Among various environmental management practices, AMTs applications are one of the most effective and popular practice (Khalili et al., 2014).Song and Wang (2017) have observed that organizations should participate in global value chain and improve production efficiency to ensure progress of AMTs. Luna et al. (2011) have observed that the implementation of AMTs adoption depends on the process of planning and monitoring. The use of outdated and ineffective technologies, insufficient manufacturing infrastructures and inadequate information about updated AMTs (Mitchell 2006; Liu 2014).

Implementation of AMTs faces many operational and strategic barriers. Barriers inhibit investments in AMTs that are energy and economically efficient (Trianni and Cagno, 2012). According to Weber (1997),barriers may be categorised as institutional barriers caused by government and regulations,barriers conditioned by the market, organisation barriers and behavioural barriers. Barriers prevent AMTs from being commercialised and dispersed which in turn restrict the financing environment (Demirel and Parris 2015; Jacobsson and Karltorp 2013; Leete et al. 2013; Polzin et al. 2016).Koefoed and Buckley (2008) have observed that in manufacturing organisations the majority of employees have only basic technical knowledge. Hamed and Mahgary (2004) have observed that lack of financial resources to implement AMTs is major barriers in manufacturing organisation of Egypt. According to Mitchel (2006), inadequacy of cash flow also influences the sustainable innovation process in organisations.

Based on literature review, four categories of barriers are identified. These are technical and information barriers, operational and strategic barriers, financial and economic barriers and human barriers. These barriers cause poor implementation of AMTs in organisations as shown in the form of cause and effect diagram in figure 5.1.

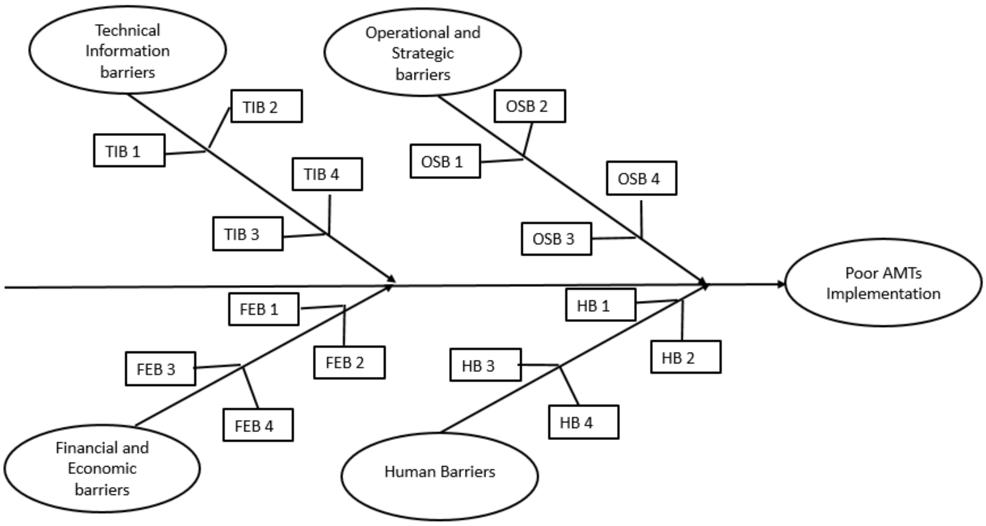

Figure 5.1: Cause and effect diagram for barriers in implementation of AMTs

Above said four category barriers considered in this study for AMTs implementation are discussed in following sections.

5.3 Research Phases for Analyzing AMTs barriers

A number of barriers hindering the implementation of AMTs are recognised based on literature review and interactions with academicians, managers of industry. For simple computation work, these barriers are categorised into different groups otherwise it will become tedious to calculate the intensity of barriers. Similar categorisation of factors has been accomplished by other researchers also in their respective studies using AHP and GTA (Anand and Bahinipati 2012; Muduli et al. 2013).

This study consists of two parts. First part deals with prioritization of barriers and second part deals with barriers intensity index. Therefore, research methodology is described in two sections: First section will describe steps of AHP and second section will describe steps of GTA. In 1972, AHP (Saaty, 1990) was developed as a realistic approach for resolving complex problems. It helps the analysts in systematizing theoretical aspects of a problem into a hierarchical structure analogous to a family tree. AHP does not only help the analysts to take an excellent decision, but also supports them with a fair justification for the decisions made by decreasing complex decisions to a series of understandable comparisons and rankings. Finally, synthesizing the conclusions. (Chin et al., 1999). Therefore, AHP has been acknowledged as a best decision method providing mathematical clarity and flexibility, for study in different fields, such as business, engineering, food, health, ecology, and government. Different phases of AHP are mentioned as following:

- Organising the problem and structuring the AHP model.
- Accumulating statistical figures from professionals.
- Deciding the normalized priority weights of individual factors and sub factors.

- Synthesis-finding resolution to problem

Phase 1: Organising a hierarchy model for prioritization of factors: This phase includes formulating a suitable hierarchy of AHP model abiding of the goal, strategic areas, sub-factors and goal is positioned on the first level of the hierarchy as shown in Figure 5.2. Four categories of barriers are identified, to accomplish this goal, which form the second level of hierarchy. The next or the third level of hierarchy consist of 16 sub-factors.

Phase 2: Measuring and assembling data: After structuring the AHP hierarchy, the consequent phase is the measurement and assimilation of data. It includes making a team of professionals and experts and assigning pair-wise comparison to the strategic areas and sub factors used in the AHP hierarchy. The nine-point scale (1-Equal importance, 9-Absolute importance of one over other), is used to designate relative scores to pair-wise comparisons amongst the strategic areas and sub factors. For this purpose, an expert team of six members was formed. This team of six experts comprised of three members from academics and three from industry. Each member had more than ten years of experience in manufacturing industry.

Phase 3: Determining-normalized weights- In the measurement and data collection phase, the pair-wise comparison judgment matrices are formed by supervision of six experts, to decide the relative significance of the categories of barriers and sub factors.

Phase 4: Synthesis-finding solution to the problem- Once the normalized priority weights are calculated for each pair-wise comparison judgment matrices of the AHP hierarchy, the next step is to incorporate the solution for prioritization of factors for different categories of barriers.

After identification of barriers, academicians, industrial professionals and government officials from board of industries of government of Haryana, India were approached for rating of barriers through GTMA. Team of eleven experts was formed for rating various factors in GTMA. It consisted of five experts from manufacturing sector, four representatives from academics, two experts from environment science. All experts were having more than 10 years of relevant experience.

5.3.1 Behavioural digraph

Jurkat and Ryser (1966) derived a matrix equation which contains multinomial, approved matrix function used and described in combinatorial mathematics. The method of calculation of the permanent function of the matrix is computed in an analogous manner as its determinant, but by converting all the negative signs that occur during determinant computation to positive signs (Grover et al., 2006), to neglect any deficit of knowledge. The representation for permanent function for four elements digraph according to Jurkat and Ryser (1966) is as follows:

$$\text{Per (K)} = \prod_{i=1}^{4} K_i + \sum_i \sum_j \sum_k \sum_l r_{ij}r_{ji}K_kK_l + \sum_i \sum_j \sum_k \sum_l (r_{ij}r_{ji}r_{ki} + r_{ik}r_{kj}r_{ji})K_l + \sum_i \sum_j \sum_k \left\{ \sum_l (r_{ij}r_{ji}) \times (r_{kl}r_{lk}) + \sum_i \sum_j \sum_k \sum_l (r_{ij}r_{jk}r_{kl}r_{li} + r_{il}r_{lk}r_{kj}r_{ji}) \right\}$$

The permanent statement includes terms organized in n + 1grouping. Here n = 4, therefore, five divisions are there, whose importance is described below.

- The first categorization includes only one term and indicates interplay of four factors, i.e. $K_1K_2K_3K_4$
- The second categorization is missing as there is no self-loop in the digraph
- The third categorization includes two terms. Every term represents two-factor interdependence, i.e $r_{ij}r_{ji}$ and evaluation of remaining n - 2 AMTs barriers
- Each term of fourth categorization indicates a set of three-factor interdependence $r_{ij}r_{jk}r_{ki}$ or its pair $r_{ik}r_{kj}r_{ji}$ and evaluate of left n -3 (i.e. 1 here) AMTs barriers.
- The terms of fifth categorizations are set in two subgroups. The first sub categorization is a set of two, two-factor interdependence, i.e. $r_{ij}r_{ji}$ and $r_{kl}r_{lk}$ measure of left n - 4 (i.e. 0 here) barriers.

The second sub categorization is a set of four-factor interdependence, i.e. $r_{ij}r_{jk}r_{kl}r_{li}$ and $r_{il}r_{lk}r_{kj}r_{ji}$ measure of left n - 4 AMTs barriers.

The behavioural factors limiting AMTs implementation are represented as a diagraph in terms of nodes and edges in figure 5.2. It is also called directed graph. K_i's factors represent nodes and factors (r_{ij}'s) represent dependence through its edge. r_{ij} represents degree of dependence of jth factor on ith factor. A directed edge from node i to node j represents r_{ij}in the digraph. The digraph allows showing the proposed behavioural factors and communication among factors. In particular, four barriers groups are recognised from the behavioural digraph. Behavioural digraph of technical information barriers group is shown in figure 5.3. The sub barriers are represented by the nodes $K^1{}_1$, $K^1{}_2$, $K^1{}_3$ and $K^1{}_4$ for the technical information barriers and interrelationship between them are represented by r_{ij}'s.

One to one representation in the cells of the matrix is given by digraph. We are approaching to express four factors limiting AMTs implementation by means of 4 ×4 matrix. The matrix for conceptual framework (D) is represented as:

$$D=\begin{pmatrix} K_1 & r_{12} & r_{13} & r_{14} \\ r_{21} & K_2 & r_{23} & r_{24} \\ r_{31} & r_{32} & K_3 & r_{34} \\ r_{41} & r_{42} & r_{43} & K_4 \end{pmatrix} \qquad (1)$$

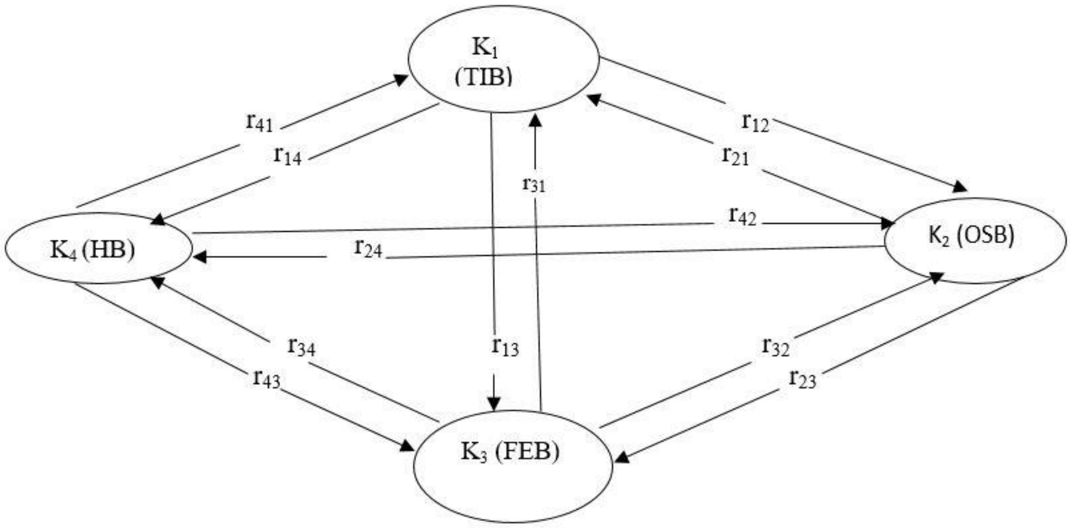

Figure 5. 2: Behavioural digraph of different categories of barriers

The permanent function (per) is evaluated for the pre said matrix for each important group of barriers as follows:

K represents the absolute values in the matrix and r represents the relative values in the matrix.

Per (K_1) = Per (Technical information barriers)

$$= \begin{pmatrix} K_1^1 & r_{12}^1 & r_{13}^1 & r_{14}^1 \\ r_{21}^1 & K_2^1 & r_{23}^1 & r_{24}^1 \\ r_{31}^1 & r_{32}^1 & K_3^1 & r_{34}^1 \\ r_{41}^1 & r_{42}^1 & r_{43}^1 & K_4^1 \end{pmatrix} \quad (2)$$

K^1_1, K^1_2, K^1_3, K^1_4 represents TEB1, TEB2, TEB3 and TEB4 (sub barriers)

Per (K_2) = Per (Operational and strategic barriers)

$$= \begin{pmatrix} K_1^2 & r_{12}^2 & r_{13}^2 & r_{14}^2 \\ r_{21}^2 & K_2^2 & r_{23}^2 & r_{24}^2 \\ r_{31}^2 & r_{32}^2 & K_3^2 & r_{34}^2 \\ r_{41}^2 & r_{42}^2 & r_{43}^2 & K_4^2 \end{pmatrix} \quad (3)$$

Per (K_3) = Per (Finance and Economic barriers)

$$= \begin{pmatrix} K_1^3 & r_{12}^3 & r_{13}^3 & r_{14}^3 \\ r_{21}^3 & K_2^3 & r_{23}^3 & r_{24}^3 \\ r_{31}^3 & r_{32}^3 & K_3^3 & r_{34}^3 \\ r_{41}^3 & r_{42}^3 & r_{43}^3 & K_4^3 \end{pmatrix} \quad (4)$$

Per (K_4) = Per (Human barriers)

$$= \begin{pmatrix} K_1^4 & r_{12}^4 & r_{13}^4 & r_{14}^4 \\ r_{21}^4 & K_2^4 & r_{23}^4 & r_{24}^4 \\ r_{31}^4 & r_{32}^4 & K_3^4 & r_{34}^4 \\ r_{41}^4 & r_{42}^4 & r_{43}^4 & K_4^4 \end{pmatrix} \quad (5)$$

For further illustration, permanent matrix value for technical information barrier can be calculated as follows:

$$\text{Per(TIB)} = \begin{pmatrix} K_1^1 & r_{12}^1 & r_{13}^1 & r_{14}^1 \\ r_{21}^1 & K_2^1 & r_{23}^1 & r_{24}^1 \\ r_{31}^1 & r_{32}^1 & K_3^1 & r_{34}^1 \\ r_{41}^1 & r_{42}^1 & r_{43}^1 & K_4^1 \end{pmatrix} \quad (6)$$

This matrix can be expanded as,

$$\begin{aligned} & K^1{}_1 K^1{}_2 K^1{}_3 K^1{}_4 + (r^1{}_{12}\, r^1{}_{21}\, K^1{}_3\, K^1{}_4 + r^1{}_{13}\, r^1{}_{31}\, K^1{}_2\, K^1{}_4 + r^1{}_{14}\, r^1{}_{41}\, K^1{}_2\, K^1{}_3 + r^1{}_{23}\, r^1{}_{32}\, K^1{}_1\, K^1{}_4 \\ & + r^1{}_{24}\, r^1{}_{42}\, K^1{}_1\, K^1{}_3 + r^1{}_{34}\, r^1{}_{43}\, K^1{}_1\, K^1{}_2) + (r^1{}_{23}\, r^1{}_{34}\, r^1{}_{42}\, K^1{}_1 + r^1{}_{24}\, r^1{}_{43}\, r^1{}_{32}\, K^1{}_1 + r^1{}_{13}\, r^1{}_{34}\, r^1{}_{41}\, K^1{}_2 \\ & + r^1{}_{14}\, r^1{}_{43}\, r^1{}_{31}\, K^1{}_2 + r^1{}_{12}\, r^1{}_{24}\, r^1{}_{41}\, K^1{}_3 + r^1{}_{14}\, r^1{}_{42}\, r^1{}_{21}\, K^1{}_3 + r^1{}_{12}\, r^1{}_{23}\, r^1{}_{31}\, K^1{}_4 + r^1{}_{13}\, r^1{}_{32}\, r^1{}_{21}\, K^1{}_4) \\ & + (r^1{}_{12}\, r^1{}_{21}\, (r^1{}_{34}\, r^1{}_{43} + r^1{}_{13}\, r^1{}_{31}\, r^1{}_{24}\, r^1{}_{42} + r^1{}_{14}\, r^1{}_{41}\, r^1{}_{23}\, r^1{}_{32} + r^1{}_{12}\, r^1{}_{23}\, r^1{}_{34}\, r^1{}_{41} + r^1{}_{14}\, r^1{}_{43}\, r^1{}_{32} r^1{}_{21} + r^1{}_{13} \\ & r^1{}_{34}\, r^1{}_{42}\, r^1{}_{21} + r^1{}_{12}\, r^1{}_{24}\, r^1{}_{43}\, r^1{}_{31} + r^1{}_{14}\, r^1{}_{42}\, r^1{}_{23}\, r^1{}_{31} + r^1{}_{13}\, r^1{}_{32}\, r^1{}_{24}\, r^1{}_{41}) \end{aligned} \quad (7)$$

5.4 Results and discussions: This research aims to assess the barriers to the implementation of Advanced Manufacturing Technologies (AMTs) through a case study of ABC Ltd., a leading manufacturing organization in the fluid transmission products sector. Established in 1970, ABC Ltd. operates eight manufacturing plants with a projected turnover of US $155 million by the fiscal year 2018-2019 and employs 300 workers. Despite its commitment to product quality and continuous improvement, the rapid pace of industrialization and technological advancements pose significant environmental challenges. To address these environmental issues, the company is exploring the use of AMTs to reduce its impact on the ecosystem. To mitigate this impact, ABC Ltd. is seeking to implement AMTs that can improve the sustainability of its operations. The utilization of advanced manufacturing technology can greatly contribute to sustainable and environmentally conscious production practices. Advanced manufacturing technology can enhance production processes by automating and optimizing them. The use of advanced manufacturing technology can aid in the management of resources, such as using more environmentally friendly materials and recycling waste, thereby reducing the environmental impact of production. Furthermore, Advanced manufacturing technology provides real-time monitoring and control, allowing manufacturers to quickly and effectively identify and address inefficiencies, waste and environmental issues. The study applies the Analytic Hierarchy Process (AHP) to prioritize the barriers to the implementation of AMTs, and then quantifies these barriers using the Graph Theoretic Approach (GTA) method. This approach will provide a comprehensive understanding of the challenges faced by the company in its pursuit of a more sustainable and environmentally responsible manufacturing process.

5.5 Prioritisation of different categories of barriers by AHP:

Construction of pair-wise comparison matrices: A set of pair-wise comparison matrices are constructed for all categories of barriers i.e. TIB, OSB, FEB and HB and sub barriers under each category. An element in the higher level is said to be a governing element for those in lower level, since it provides to it or influences it. The elements in the lower level are then compared to each other based on their effect on the governing element above. This yields a square matrix of judgments. These pair wise comparison matrices are shown in Tables 5.1 to 5.5.

Table 5.1:Pair wise comparison judgement matrix

	TIB	OSB	FEB	HB	PV
TIB	1	1/3	¼	½	0.0930
OSB	3	1	1/3	2	0.2389
FEB	4	3	1	4	0.5249
HB	2	½	1/41	1	0.1433
TOTAL	10	4.833	1.833	7.5	CR = 0.04

Table 5.2:Pair wise comparison judgement matrix of TIB

	TIB1	TIB2	TIB3	TIB4	PV
TIB1	1	1/5	1/3	1/3	0.086
TIB2	5	1	2	1/3	0.290
TIB3	3	½	1	½	0.194
TIB4	3	3	2	1	0.431
TOTAL	12	4.7	5.333	2.166	CR < 0.1

Table 5. 3: Pair wise comparison judgement matrix of OSB

	OSB1	OSB2	OSB3	OSB4	PV
OSB1	1	3	5	1/3	0.2996
OSB2	1/3	1	½	1/5	0.0810
OSB3	1/5	2	1	1/3	0.1275
OSB4	3	5	3	1	0.4920
TOTAL	4.533	11	9.5	1.866	CR< 0.1

Table 5.4: Pair wise comparison judgement matrices of FEB

	FEB1	FEB2	FEB3	FEB4	PV
FEB1	1	1/3	3	½	0.210
FEB2	3	1	½	1/3	0.213
FEB3	1/3	2	1	1/3	0.164
FEB4	2	3	3	1	0.413
TOTAL	6.331	6.33	7.5	2.167	CR<0.1

Table 5.5: Pair wise comparison judgement matrix of HB

	HB1	HB2	HB3	HB4	PV
HB1	1	1/3	2	¼	0.142
HB2	3	1	2	1/3	0.246
HB3	½	½	1	1/3	0.115
HB4	4	3	3	1	0.467
TOTAL	8.5	4.833	8	1.91	CR <0.1

There are n (n-1)/2 judgment necessary to expand the set of matrices. It is known that human are generally inconsistent in answering queries, and thus one of the important function of AHP is to evaluate the consistency level of the estimated vector. Consistency ratio (CR) is used to measure the consistency in the pair-wise comparison. Saaty (1994) has set the acceptable CR value for different matrices sizes. The CR value is 0.05 for a 3-by-3 matrix 0.08 for a 4-by-4 matrix; and 0.1 for large matrices. As CR for all matrices is less than 10 percent, therefore judgments are considered consistent.

Table 5.6: Global weights of the different categories of barriers and sub barriers

Categories of Barriers	Local weights	Global weights
1. Technical Information Barrier	0.0930	0.0930
a) lack of access to external technical support and knowledge	0.086	0.008
b) Lack of awareness about AMTs and industrial revolution	0.290	0.0270
c) Lack of upgradation of machines and tools	0.194	0.0180
d) Lack of skilled workforce	0.431	0.0401
2) Operational and strategic barriers	0.2389	0.2389
a)Lack of support for technology innovations	0.2996	0.0716
b) Lack of awareness of sustainable operations	0.0810	0.0193
c) Lack of sustainability measures	0.1275	0.0304
d) Lack of long term planning	0.4920	0.1175
3) Financial and economic barriers	0.5249	0.5249
a) Lack of dedicated financial budget for AMTs	0.210	0.1102
b) Difficulty in accessing financing	0.213	0.1118
c) Lack of economic incentive policies	0.164	0.0860
d) Lack of internal accounting and auditing	0.413	0.2168
4) Human Barriers	0.1433	0.1433
a) Difficulties linked to new learning processes	0.142	0.0203
b) Lack of fear of government regulations	0.246	0.0352
c) Lack of involvement of work force	0.115	0.0164
d) Fear of losing flexibility and authority	0.467	0.0669

Table 5.6 shows the global weights of the different categories of barriers and it also gives the global weights of the sub factors for different categories of barriers. Financial and economic barriers (0.5249) are found to be most severe category of barriers followed by the operational and strategic barriers (0.2389), human barriers (0.1433) and technical information barriers (0.0930). At sub factors level, lack of skilled workforce, lack of long-term planning, lack of internal accounting and auditing, fear of losing flexibility and authority are major barriers in implementation of AMTs. It is usually observed that organisations do not make long term planning in deciding about new technologies. They look into short term benefits for meeting compelling market requirements. Organisations also not make investment in training workforce for adopting advanced technologies such as Internet of things; cloud computing, artificial intelligence, cyber physical systems in era of Industry 4.0 environment.

5.6 Barriers intensity index by GTMA

This section will try to find intensity index value of all categories of barriers. These categories of barriers are TIB, OSB, FEB and HB. For developing permanent technical information barrier matrix, sub barriers are placed in diagonal cell of the matrix. These are rated on scale of 1 to 5 based on respective intensity of barriers for each case. Here 1 denotes very low and 5 denotes very high. For other remaining cells in the matrix, relative values are placed on scale of 1-10 as per described scale in table 5.1. Using formula $r_{ji} = 10 - r_{ij}$, where i represents number of row and j represents number of columns of the matrix. On the basis of this concept different absolute and relative values of barriers in the matrix are taken based on the input given by team of experts of the industry and equation 8 is developed. After calculating index value of individual category of barriers, overall AMTs barrier index value will be evaluated.

To evaluate permanent matrix index of technical information barriers for digraph as shown in figure 5.5, inputs for corresponding absolute and relative values are taken with the help of team of experts. These values are as follows:

$K_1^1 = 3$, $K_2^1 = 4$, $K_3^1 = 3$, $K_4^1 = 2$ (Absolute values of barriers)

$r_{12}^1 = 4$ $r_{13}^1 = 5$ $r_{14}^1 = 6$, $r_{21}^1 = 6$ $r_{23}^1 = 6$ $r_{24}^1 = 7$, $r_{31}^1 = 5$ $r_{32}^1 = 4$ $r_{34}^1 = 6$, $r_{41}^1 = 4$ $r_{42}^1 = 3$ $r_{43}^1 = 4$ (Relative values of barriers).

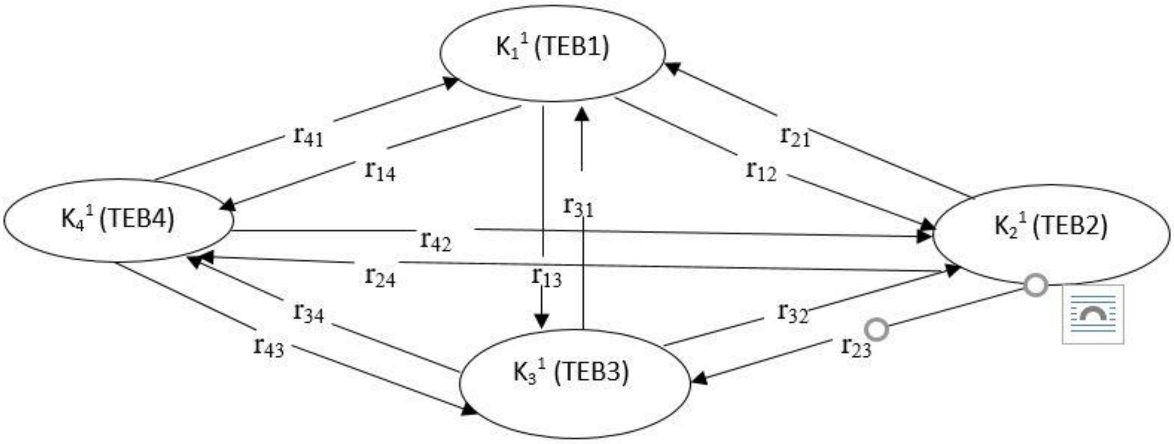

Figure 5.3: Digraph for Technical information barrier

Therefore, numerical values for Permanent matrix of (TIB) i.e per TIB will be calculated as follows.

$$\text{Per (TIB)} = \begin{pmatrix} 3 & 4 & 5 & 6 \\ 6 & 4 & 6 & 7 \\ 5 & 4 & 3 & 6 \\ 4 & 3 & 4 & 2 \end{pmatrix}$$

Per (TIB)=
3.4.3.2 + (4.6.3.2+ 5.5.4.2+ 6.4.4.2 + 6.4.3.2+ 7.3.3.3+ 6.4.3.4) + (6.6.3.3+ 7.4.4.3 + 5.6.4.4 + 6.4.5.4 + 4.7.4.3 + 6.3.6.3 + 4.6.5.2 + 5.4.6.2 + (4.6.6.4 + 5.5.7.3 + 6.4.6.4 + (8)
4.6.6.4 + 6.4.4.6 + 5.6.3.6 + 4.7.4.5 + 6.3.6.5 + 5.4.7.4)
= 8970

Similarly, permanent matrix values of other categories of barriers are calculated.

Permanent matrix value for operational and strategic barriers can be calculated as follows based on inputs taken from the team of experts.

$K_1^2 = 3,\ K_2^2 = 4,\ K_3^2 = 4,\ K_4^2 = 2$

$r_{12}^2 = 3\ r_{13}^2 = 4\ r_{14}^2 = 2,\ r_{21}^2 = 7\ r_{23}^2 = 5\ r_{24}^2 = 3,\quad r_{31}^2 = 6\ r_{32}^2 = 5\ r_{34}^2 = 4,\ r_{41}^2 = 8\ r_{42}^2 = 7\ r_{43}^2 = 5$

$$\text{Per (OSB)} = \begin{pmatrix} 3 & 3 & 4 & 2 \\ 7 & 4 & 5 & 3 \\ 6 & 5 & 4 & 4 \\ 8 & 7 & 6 & 5 \end{pmatrix} = 9947 \qquad (9)$$

Permanent matrix value for financial and economic barriers can be calculated as follows based on inputs taken from the team of experts.

$K_1^3 = 5,\ \ K_2^3 = 3,\ K_3^3 = 5,\ K_4^3 = 4,$

$r_{12}^3 = 7\ \ r_{13}^3 = 6\ r_{14}^3 = 6,\ r_{21}^3 = 3\ r_{23}^3 = 3\ r_{24}^3 = 4,\ r_{31}^3 = 4\ r_{32}^3 = 7\ r_{34}^3 = 7,\ r_{41}^3 = 4\ r_{42}^3 = 6\ r_{43}^3 = 5$

$$\text{Per (FEB)} = \begin{pmatrix} 5 & 7 & 6 & 6 \\ 3 & 3 & 3 & 4 \\ 4 & 7 & 5 & 7 \\ 4 & 6 & 5 & 4 \end{pmatrix} = 10876 \qquad (10)$$

Permanent matrix value for human barriers can be calculated as follows based on inputs taken from the team of experts.

$K_1^4 = 3,\ \ K_2^4 = 3,\ K_3^4 = 5,\ K_4^4 = 4$

$r_{12}^4 = 5\ \ r_{13}^4 = 3\ r_{14}^4 = 4,\ r_{21}^4 = 5\ r_{23}^4 = 2\ r_{24}^4 = 4,\ r_{31}^4 = 7\ r_{32}^4 = 8\ r_{34}^4 = 7,\ r_{41}^4 = 6\ r_{42}^4 = 6\ r_{43}^4 = 3$

$$\text{Per (HB)} = \begin{pmatrix} 3 & 5 & 3 & 4 \\ 5 & 3 & 2 & 4 \\ 7 & 8 & 5 & 7 \\ 6 & 6 & 3 & 4 \end{pmatrix} = 9438 \qquad (11)$$

On the similar line, the overall AMTs barriers intensity index (CBI) value can be computed by following permanent matrix.

$$\text{Per(CBI)} = \begin{pmatrix} 8970 & 6 & 5 & 7 \\ 4 & 9947 & 4 & 7 \\ 5 & 6 & 10876 & 8 \\ 3 & 3 & 2 & 9948 \end{pmatrix} = 9.16 \times 10^{15} \qquad (12)$$

Minimum theoretical barrier index:

According to Muduli et al. (2013), for theoretical minimum value of different categories of barriers, the diagonal cells of the decision matrix are kept unity and remaining other cells are kept 5. Minimum value for category 1 barriers i.e. (Technical Information Barriers) for implementing AMTs in manufacturing organisation will be as follows:

$$B_1 = \begin{pmatrix} 1 & 5 & 5 & 5 \\ 5 & 1 & 5 & 5 \\ 5 & 5 & 1 & 5 \\ 5 & 5 & 5 & 1 \end{pmatrix} = 6776 \qquad (13)$$

Similarly, theoretical minimum value of other categories of barriers will be same.

***Maximum theoretical barrier index*:**

According to Muduli et al. (2013), the theoretical maximum value for different categories of barriers intensity is found when the inheritance of all its sub factors have maximum value i.e. 5, in this case.

Maximum value for category 1barrier i.e. Technical information barriers for manufacturing organisation will be as follows:

$$W_1 = \begin{pmatrix} 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \end{pmatrix} = 15000 \qquad (14)$$

Similarly, theoretical maximum value of other categories of barriers will be same.

Index value of various categories of barriers of AMTs application along with minimum and maximum values have been calculated as per equation 6 and equations 9-14. These values are summarised in table 5.8 and figure 5.4.

Table 5.8: Index values of different category of barriers

Barriers / Index Value	Technical information barriers	Operational and strategic barriers	Finance and economic barriers	Human barriers	Overall AMTs barriers index
Index value	8970	9947	10876	9438	9.6×10^{15}

Figure 5.4: Graphical representation of maximum, minimum and index value of different category of barriers

The degree of adverse impact of a particular category of barriers on AMTs applications is represented by index value. Higher value of index represents high intensity of barriers to AMTs, whereas lower value of index represents lesser intensity of barriers in AMTs implementation. It is observed from the figure 5.4 that category 3 of barriers (Finance and economic barriers) has highest intensity and category 1 of barriers (Technical information barriers) has the least intensity. Hence barriers of category 3 (Finance and economic barriers), must be given more importance followed by barriers of category 2(Operational and strategic barriers), barriers of category of 4 (Human barriers) and finally barriers of category 1 (Technical information barriers). Findings imply that top management should ensure sufficient dedicated budget for application of AMTs and other initiatives. Internal accounting and audit process should be smooth. To overcome operational and strategic barriers, management should have long term planning for ensuring sustainable performance. Performance framework should emphasize on sustainability measures and operations for whole value chain. To ensure sustainability, awareness about its long term benefits and support for technological innovations should be encouraged. Shi et al. (2008) have tried to analyse barriers for implementation of AMTs in Chinese SMEs and found lack of economic incentive policies; lax environmental enforcement, and high initial capital cost as major barriers in this process. It was observed that most companies in Vietnam do not have the financial capacity to implement new technologies (VNCPC, 2000). It implies that financial barriers in implementing advanced AMTs are prominent in other countries also.

In context to Industry 4.0 environment, new technologies such as Internet of Things (IOTs), big data analytics, artificial intelligence and machine learning are being popular for different manufacturing operations. These new technologies not only improve functional efficiency but are also considered more sustainable in terms of lesser pollution and resource consumption. Findings of this study imply that learning culture for new technologies applications should be created within organisation and fear among workforce should be eliminated. Organisations should be made flexible to adopt these changes. Many organisations focus on short term goals thereby ignore sustainability initiatives like implementing advanced technologies due to the fear of heavy investment and risks of failure. Prevailing organisation culture also play crucial role in motivating employees for sustainable operations and initiatives (Govindarajulu and Daily, 2004). Workers should be also trained about business ethics. Gunasekaran and Spalanzani (2012) have observed that strong business ethics help in success of sustainability initiatives such as implementation of AMTs.

Luthra and Mangla (2018) have observed that support from top management in all initiatives and its involvement is essential for successful implementation of AMTs. Government may also play crucial role by incentivising sustainability initiatives. Top management needs to develop effective corporate strategy and involve in successful implementation of these advanced technologies (Griffiths and Petrick, 2001). Proper planning for implementing AMTs in different processes and its continuous monitoring is necessary to ensure its success. Strategic planning facilitates proactive decision-making to evaluate performance and to implement strategies for sustainability goals (Mudgal et al., 2010). Strategy should support technological innovations, awareness about sustainability and long term goals. To encourage technological innovations in organization, management should need to motivate research and development, skill up gradation and continuous training (Barve et al., 2009).

5.7 Concluding Remarks

Overall this study has tried to prioritise the different categories of barriers and quantify impact of barriers in AMTs implementation through systematic approach. Findings of this research may contribute in ensuring AMTs for sustainable competitive advantages but it has got some limitations. Development of the permanent matrix equation of AMTs implementation barriers is complex and lengthy when barriers are more in number. Absolute and relative values considered while quantifying the intensity of barriers are based on experts' opinion, which may be inconsistent. The next chapter talks about critical success factors for implementing AMTs.

Chapter-6: Prioritizing Critical Success Factors for implementation of Advanced Manufacturing Technologies

6.1 Introduction:

Changing customer demand patterns and globalized competition in the manufacturing landscape have urge the manufacturing industries to go for state-of-art tools and techniques (Singh and Gurtu, 2021). Also, looking at intensified competition and dynamic market scenario, it has become essential for the organizations to realign their manufacturing operations (Yadav et al., 2020). Therefore, organizations across the world are much more focusing on Advanced Manufacturing Technologies (AMTs) like Industry 4.0. Getting quality product is the first and foremost priority of each customer. In 1970's, the competition was extremely less; product variety and production volume were also less (Bhandari et al., 2018). During that era, there were limited number of producers but large number of buyers. Customers had to wait for getting their product ready. But in the present market scenario, there is intense competition. Advanced technologies and digital transformations have resulted in increased process capability and overall efficiency of the industries. So, now a days the customers can expect highly quality products at reasonable prices. Therefore, industries are being compelled towards these high-end technologies and digital transformation to keep themselves in this competitive marketplace (Cheng et al., 2018). In the current scenario, industries are using various advanced manufacturing technologies like Electric Discharge Machining, Rapid Prototyping, Robotics, Augmented Reality, Virtual Reality, Electro Chemical Machining, Abrasive Jet Machining. Available scholarly literature reveals that adopting these advanced manufacturing technologies is not so simple, industrialists encounter various barriers while its implementation. Bhise and Sunnapawar (2019) discussed the issues arise in AMTs implementation, the authors bifurcated implementation into three phases, planning & justification phase, pre-implementation and post implementation phase. Investments made in advanced manufacturing facilities have resulted in plethora of benefits which includes improved quality of products and employee morale, reduced manufacturing lead time and cost, increased profitability, efficiency and effectiveness (Cagliano and Spina, 2000; Bulbul et al., 2013; Ford and Despeisse, 2016; Diaz-Reza et al., 2019). Additionally, the manufacturing setup can be reconfigured as per changing demand patterns of the customers in negligible amount of time.

The convoluted implementation patterns of AMTs have urged the mangers to adopt strategic tools and techniques for its effective and efficient implementation. Chen and Small (1994) highlighted that huge investment incurred in AMTs can be risky venture, so risk mitigation strategies must be adopted. Barua and Islam (2008) identified CSFs of Advanced Manufacturing Technologies (AMTs) in pharmaceutical industry. The authors categorized CSF's into three categories: Human, Technological and Strategic. In the presented research, the critical success factors have been identified in manufacturing industries. Major role in industrial development is played by industries in both developed as well as developing countries (Rosnah et al., 2004).

Manufacturing era is going through transformation phase. At present, so many advanced and digital technologies are introduced in the marketplace. Extant literature reveals the operational benefits of implementing AMTs includes reduced manufacturing lead time, increased profitability, increased market share, improved operational efficiency (Boyer et al., 1997). But as stated by various researchers, implementation of AMTs is not complacent, dedicated efforts from stakeholders are required to make its implementation journey successful. So, it is very necessary for the industries to identify and evaluate critical success factors. Keeping in view these perspectives, the research questions were framed as follows:

RQ1. To identify CSFs affecting AMTs adoption in industries

RQ2. To prioritize the CSFs so that AMTs can be implemented effectively and efficiently.

6.2 Exploration of CSFs of AMTs

To enhance the effectiveness and efficiency, analysing CSFs of AMTs play significant role. It is evident from the scholarly literature that strategic planning results in design the process much better and resulting in effective adoption of advanced manufacturing technologies. CSFs and performance indicators were explored using scholarly literature. Various research databases investigated were Scopus, Google Scholar, Web of Science, EBSCO Host etc. The list of CSFs are discussed in chapter-2, section 2.10 and performance indicators in section 2.11.

Table 6. 1: Critical success factor for implementing Advanced Manufacturing Technologies

S.No	Critical success Factors	References
1	Skills and Expertise development to implement AMTs	Sambasivarao and Deshmukh (1995), Kumar et al. (2017), Mathew et al. (2020)
2	Readiness for organisational change to adopt AMTs	Jonsson (2000), Ghani et al. (2002), Raj et al. (2019)
3	Organisational culture	Kumar et al. (2017), De Sousa Jabbour et al. (2018), Sambasivarao and Deshmukh (1995) , Singh et al. (2007)
4	Strategic planning for implementing AMTs	Dwivedi et al. (2017), Chen and Small (1994), Sambasivarao and Deshmukh (1995)
5	Top management commitment for AMTs implementation	Chen and Small (1994), Dwivedi et al. (2017), Sambasivarao and Singh et al. (2007)
6	Empowerment of employees for decision making	Dean et al. (1992), Sacristán Díaz et al. (2003), Dutta et al. (2021)
7	Integration and coordination between different departments	Boyer and Pagell (2000), Singh et al. (2007), Dutta et al. (2021)
8	Dedicated funds allocation for AMTs	Kumar et al. (2017), Saliba et al. (2017), Sambasivarao and Deshmukh (1995)
9	Government policies for implementing AMTs	De Rosa Cardoso et al. (2012), Storenelli et al. (2021)
10	Economic sustainability of AMTs	Kamble et al. (2018); Mathew et al. (2020)
11	Performance measures for monitoring and evaluation performances	Raymond (2005), Mathew et al. (2020)
12	Clear understanding of strategic goals, vision, and objectives	Abd Rahmana (2008), Zhou et al. (2009), De Rosa Cardoso et al. (2012), Sambasivarao and Deshmukh (1995), Singh et al. (2007)

13	Use of continuous improvement systems	Abd Rahmana (2008), De Rosa Cardoso et al. (2012), De Sousa Jabbour et al. (2018), Sambasivarao and Deshmukh (1995)
14	Mutual trust and collaboration among all stake holders.	Singh et al. (2007), De Sousa Jabbour et al. (2018), Sambasivarao and Deshmukh (1995)
15	Training and Educational Programs	De Rosa Cardoso et al. (2012), De Sousa Jabbour et al. (2018)

6.3 Performance Factors

The adoption of Advanced Manufacturing Technologies (AMTs) can yield several crucial performance factors for organizations. Cost reduction is highly significant parameter by optimum production processes, decreasing labor obligations, and minimizing material waste. Moreover, organizations can increase their agility in processes through the acceptance of AMTs, permitting them to promptly reply and adjust to changing market demands. Addotionaly, AMTs foster green operations by optimum energy usage, reducing emissions, and minimizing the environmental impact of manufacturing processes. Also, the implementation of AMTs can lead to an enhancement in product quality, as these technologies presents accuracy and reliability, leading to reduced defects and enhanced customer satisfaction. Last buth not the least, AMTs can omcrease an organization's resilience, facilitating them to overcome disruptions and uphold stable operations during complex situations. Therefore, performance factors integration make AMTs a significant opportunity for organizations looking to stay modest and attain long-term accomplishment in the dynamic market landscape.

Table 6.2: Performance Factors

Performance factors	References
Cost reduction	Cook and Cook (1994), Gouvea Da Costa et al. (2006), Borregan-Alvarado et al. (2020)
Agility in processes	Gunasekaran et al. (2019)
Sustainable operations	Boyer et al. (1996, 1997), Bhise and Sunnapwar (2019)
Improvement in the product quality	Dangayach and Deshmukh (2005), Singh et al. (2007)
Resilience	Singh and Gurtu (2021)

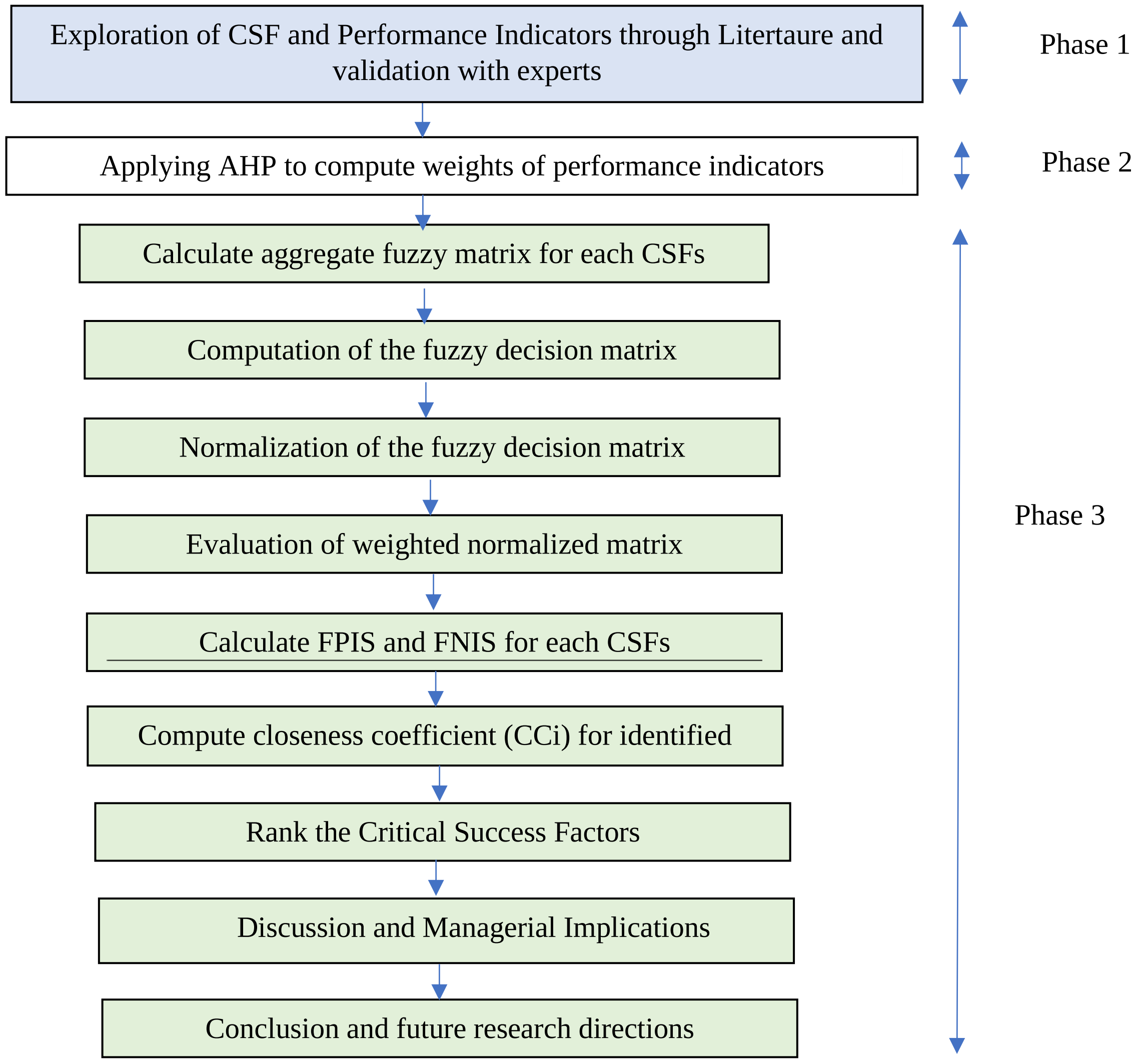

Figure 6.1: AHP-fuzzy TOPSIS Framework

Table 6.3: TFN Number of Linguistic Variables

Linguistic Variable	Triangular Fuzzy Number
Very High Importance	(1,1,3)
High Importance	(1,3,5)
Moderate Importance	(3,5,7)
Low Importance	(5,7,9)
Very Low Importance	(7,9,11)

6.4 Relationship between AMTs and Sustainability

In a global market landscape, sustainability has emerged as crucial concern which needs attention (Yadav et al., 2020). AMTs have pivotal contribution in enhancing the organization competitiveness and sustainability (Hu et al., 2022). AMTs helps to reduce energy utilization, wastages, cost and time (Kong et al., 2016). Scholarly literature (Hu et al., 2022; Kamble et al., 2018) reveals that AMTs results in enhancing innovation capabilities which ultimately helps to achieve sustainability. Sustainability dimensions (social, economic and environmental) have strong connection with latest technological advancements in manufacturing processes including robotics, automation, Internet of Things, virtual reality (Bai et al., 2020). Similar results were reported by Lin (2018), who reported the role of Industry 4.0 in achieving sustainability. On the similar note, Industry 4.0 solutions to enhance sustainable development goals were reported as product optimization, strategic planning for effective data and information sharing, strong collaboration among stakeholders, transparency and traceability of information, better working environment and employee safety, optimized supply chain network design etc. (Strandhagen et al., 2022).

6.5 Application of the proposed framework

The application is framed in to three phases:

Phase1: Identification of Critical Success Factors (CSF) and Performance Factors (PF)

CSF and PF of advanced manufacturing methods were identified through extensive literature review. Expert panel was composed of eight area experts from automobile industries which includes two CEO, one production manager, two research and development head and three design and development heads. In this study 15 CSF's and 5 PF's were finalized based on expert's opinion.

Phase 2: Computation of weights of Performance Factors using AHP

In this, experts were asked to make pairwise comparison using values as mentioned in Table 5. The weights of PF's are revealed in Table 6.4.

Phase 3: Ranking Critical Success Factors in respect of Performance Factors using fuzzy-TOPSIS using standard methodology

6.5.1 Calculations Involved

Pairwise comparison of performance indicators is shown in Table 6.1. In the next step, priority significance is computed as shown in Table 6.2

Table 6.4: Pair wise comparison matrix

	SO	CR	SO	IQP	RE	P.V
SO	1	½	3	2	3	0.265
CR	2	1	3	2	4	0.367
IQP	1/3	1/3	1	½	2	0.111
AP	½	½	2	1	3	0.185
RE	1/3	¼	½	1/3	1	0.073
	4.167	2.583	9.5	5.833	13	

$\lambda_{max=}$ 5.136

CI= (λ_{max} - M) /(M-1)

=5.136 -5 / 4 = 0.027

- CR(Consistency Ratio)=CI/RCI

  = 0.027/1.12

  = 0.024

= 2.4%

Where RCI=Random Consistency Index

Table 6.5: Desirability index of global priority

Sr.no.	Factors	PS
1	SO	0.265
2	CR	0.367
3	IQP	0.111
4	AP	0.185
5	RE	0.073

Among five performance factors, Sustainable operations got highest value, followed by Customer reduction, followed by improvement in quality of the product, followed by Agility in process and Resilience.

Table 6.6 shows linguistic scale evaluation matrix which is constructed given by expert 1. Only, linguistic values of expert 1 is shown here due to word limits. These linguistic values are converted using Triangular Fuzzy Number (TFN) to develop fuzzy computation matrix. Aggregated fuzzy matrix is developed by combining the responses of all area experts and is shown in Table 6.7. After that, normalized fuzzy decision matrix is obtained using equation (5-6) and is shown in Table 6.8. Weighted fuzzy matrix computations by multiplying the weights of performance indicators and is shown in Table 6.9.

The next step is to evaluate Fuzzy Positive Ideal Solution (FPIS, C*) and Fuzzy Negative Ideal Solution (FNIS, A^-) as $\tilde{f}^* = (0,0,0)\ and\ \tilde{f}^- = (1,1,1)$ using equation (11-12). For instance,

$$d(C_1, C^*) = \sqrt{\frac{1}{3}(0-0.16682)^2 + (0-0.27358)^2 + (0-0.367)^2} = 0.2812$$

$$d(C_1, C^1) = \sqrt{\frac{1}{3}(1-0.16682)^2 + (1-0.27358)^2 + (1-0.367)^2} = 0.73543$$

Similarly, other performance factors are evaluated with respect to CSF. For first CSF, the values of n_i^+= 4.3406 and n_i^-= 0.71233.

The closeness coefficient (using equation 13) for CSF 1 can be computed as $CC_i = \frac{n_i^-}{n_i^- + n_i^+} =$

$\frac{0.71233}{(4.3406 + 0.71233)}$ = 0.1409. The ranking of CSF is shown in Table 6.10.

Table 6.6: Linguistic Scale Evaluation Matrix for Expert-1

Expert1					
CSF	**S1**	**S2**	**S3**	**S4**	**S5**
CSF1	VH	H	VH	M	VL
CSF2	L	VH	H	H	M
CSF3	H	VH	H	VH	H
CSF4	VH	VH	H	VH	H
CSF5	VH	H	H	VH	VH
CSF6	H	H	VH	VH	H
CSF7	VH	VH	H	M	H
CSF8	H	M	VH	H	H
CSF9	M	L	L	M	H
CSF10	VH	H	H	M	M
CSF11	H	H	M	H	VH
CSF12	VH	H	VH	H	H
CSF13	H	VH	H	VH	H
CSF14	H	H	VH	VH	H
CSF15	VH	H	H	M	H

Table 6.7: Aggregated Fuzzy Matrix

	S1			S2			S3			S4			S5		
CSF1	5	8.2	11	3	7	11	5	8.2	11	3	6.6	11	1	2.2	5
CSF2	1	5	9	5	8.2	11	5	7.8	11	5	7.8	11	3	5.8	9
CSF3	5	7.4	11	5	8.2	11	5	7.8	11	5	7.8	11	5	8.2	11
CSF4	5	8.2	11	5	8.6	11	5	7.8	11	5	7.8	11	5	7.8	11
CSF5	5	8.2	11	5	7.8	11	5	7.8	11	5	8.2	11	5	8.2	11
CSF6	5	7.8	11	5	7.8	11	5	8.2	11	5	8.2	11	5	7.4	11
CSF7	5	8.2	11	5	8.6	11	5	7.8	11	3	6.2	11	5	7.4	11
CSF8	5	8.2	11	3	7	11	5	7.8	11	3	6.6	9	5	7.4	11
CSF9	3	7.4	11	1	2.2	5	1	2.2	5	1	3	7	3	7	11
CSF10	5	7.8	11	3	7	11	5	8.2	11	1	3.8	7	3	4.6	9
CSF11	3	6.2	9	5	7.8	11	3	7	11	3	7	11	3	6.6	11
CSF12	5	8.2	11	5	7.8	11	5	7.8	11	5	7.8	11	3	8.2	11
CSF13	5	7.8	11	5	7.8	11	5	7.8	11	5	8.2	11	5	7.8	11
CSF14	5	7.8	11	5	7.8	11	5	8.2	11	5	7.8	11	5	7.8	11
CSF15	5	7.8	11	5	7.8	11	5	8.2	11	3	7.4	11	5	7.8	11

Table 6.8: Normalized Matrix

	S1			S2			S3			S4			S5		
CSF1	0.45	0.75	1.00	0.27	0.64	1.00	0.45	0.75	1.00	0.27	0.60	1.00	0.09	0.20	0.45
CSF2	0.09	0.45	0.82	0.45	0.75	1.00	0.45	0.71	1.00	0.45	0.71	1.00	0.27	0.53	0.82
CSF3	0.45	0.67	1.00	0.45	0.75	1.00	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.75	1.00
CSF4	0.45	0.75	1.00	0.45	0.78	1.00	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.71	1.00
CSF5	0.45	0.75	1.00	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.75	1.00	0.45	0.75	1.00
CSF6	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.75	1.00	0.45	0.75	1.00	0.45	0.67	1.00
CSF7	0.45	0.75	1.00	0.45	0.78	1.00	0.45	0.71	1.00	0.27	0.56	1.00	0.45	0.67	1.00
CSF8	0.45	0.75	1.00	0.27	0.64	1.00	0.45	0.71	1.00	0.27	0.60	0.82	0.45	0.67	1.00
CSF9	0.27	0.67	1.00	0.09	0.20	0.45	0.09	0.20	0.45	0.09	0.27	0.64	0.27	0.64	1.00
CSF10	0.45	0.71	1.00	0.27	0.64	1.00	0.45	0.75	1.00	0.09	0.35	0.64	0.27	0.42	0.82

CSF11	0.27	0.56	0.82	0.45	0.71	1.00	0.27	0.64	1.00	0.27	0.64	1.00	0.27	0.60	1.00
CSF12	0.45	0.75	1.00	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.71	1.00	0.27	0.75	1.00
CSF13	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.75	1.00	0.45	0.71	1.00
CSF14	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.75	1.00	0.45	0.71	1.00	0.45	0.71	1.00
CSF15	0.45	0.71	1.00	0.45	0.71	1.00	0.45	0.75	1.00	0.27	0.67	1.00	0.45	0.71	1.00

Table 6.9: Weighted Normalized Matrix

	S1			S2			S3			S4			S5		
CSF1	0.17	0.27	0.37	0.05	0.12	0.19	0.12	0.20	0.27	0.03	0.07	0.11	0.01	0.01	0.03
CSF2	0.03	0.17	0.30	0.08	0.14	0.19	0.12	0.19	0.27	0.05	0.08	0.11	0.02	0.04	0.06
CSF3	0.17	0.25	0.37	0.08	0.14	0.19	0.12	0.19	0.27	0.05	0.08	0.11	0.03	0.05	0.07
CSF4	0.17	0.27	0.37	0.08	0.14	0.19	0.12	0.19	0.27	0.05	0.08	0.11	0.03	0.05	0.07
CSF5	0.17	0.27	0.37	0.08	0.13	0.19	0.12	0.19	0.27	0.05	0.08	0.11	0.03	0.05	0.07
CSF6	0.17	0.26	0.37	0.08	0.13	0.19	0.12	0.20	0.27	0.05	0.08	0.11	0.03	0.05	0.07
CSF7	0.17	0.27	0.37	0.08	0.14	0.19	0.12	0.19	0.27	0.03	0.06	0.11	0.03	0.05	0.07
CSF8	0.17	0.27	0.37	0.05	0.12	0.19	0.12	0.19	0.27	0.03	0.07	0.09	0.03	0.05	0.07
CSF9	0.10	0.25	0.37	0.02	0.04	0.08	0.02	0.05	0.12	0.01	0.03	0.07	0.02	0.05	0.07
CSF10	0.17	0.26	0.37	0.05	0.12	0.19	0.12	0.20	0.27	0.01	0.04	0.07	0.02	0.03	0.06
CSF11	0.10	0.21	0.30	0.08	0.13	0.19	0.07	0.17	0.27	0.03	0.07	0.11	0.02	0.04	0.07
CSF12	0.17	0.27	0.37	0.08	0.13	0.19	0.12	0.19	0.27	0.05	0.08	0.11	0.02	0.05	0.07
CSF13	0.17	0.26	0.37	0.08	0.13	0.19	0.12	0.19	0.27	0.05	0.08	0.11	0.03	0.05	0.07
CSF14	0.17	0.26	0.37	0.08	0.13	0.19	0.12	0.20	0.27	0.05	0.08	0.11	0.03	0.05	0.07
CSF15	0.17	0.26	0.37	0.08	0.13	0.19	0.12	0.20	0.27	0.03	0.07	0.11	0.03	0.05	0.07

Table 6.10: Final ranking of CSF of AMTS

CSF	**Description of CSF**	**ni+**	**ni-**	**ni+ + ni-**	**ni-/(ni- +ni+)**	**Rank**
CSF1	Skills and Expertise development to implement AMTs	4.34	0.712	5.053	0.141	11
CSF2	Readiness for organisational change to adopt AMTs	4.398	0.667	5.065	0.132	14
CSF3	Organisational culture	4.288	0.754	5.042	0.15	8
CSF4	Strategic planning for implementing AMTs	4.277	0.764	5.042	0.152	1

CSF5	Top management commitment for AMTs implementation	4.28	0.762	5.042	0.151	2
CSF6	Empowerment of employees for decision making	4.283	0.759	5.042	0.151	3
CSF7	Integration and coordination between different departments	4.291	0.755	5.046	0.15	7
CSF8	Dedicated funds allocation for AMTs	4.317	0.733	5.049	0.145	10
CSF9	Government policies for implementing AMTs	4.576	0.489	5.065	0.097	15
CSF10	Economic sustainability of AMTs	4.356	0.697	5.053	0.138	12
CSF11	Performance measures for monitoring and evaluation performances	4.389	0.672	5.062	0.133	13
CSF12	Clear understanding of strategic goals, vision and objectives	4.285	0.759	5.044	0.15	6
CSF13	Use of continuous improvement systems	4.285	0.757	5.042	0.15	5
CSF14	Mutual trust and collaboration among all stake holders.	4.283	0.759	5.042	0.15	4
CSF15	Training and Educational Programs	4.291	0.754	5.045	0.149	9

6.5.2 Sensitivity Analysis

To confirm the reliability of CSFs raking, sensitivity analysis is done. The closeness coefficient values are shown in Table 6.10 and figure 6.2. Total six trials S1, S2, S3, S4, S5 and S6 were carried out. In the first sensitivity analysis, first performance indicator was assigned higher weight of 0.4, while remaining four were assigned equal weights equal to 0.15. As a result, Strategic planning for implementing AMTs (CSF 4) and Top management commitment for AMTs implementation (CSF 5) still remain the top most CSFs. Similarly, in the second iteration, second performance indicator was assigned higher weight of 0.4, while the remaining four were assigned equal weights. This cycle is repeated five times. In the last iteration, all performance indicators were assigned equal weights equal to 0.2. It is included that by varying the weights of performance indicators, the ranking of CSFs remains unchanged. Table 6.11 shows the closeness coefficient values of CSFs in sensitivity analysis.

Table 6.11: Closeness coefficient values of CSFs in sensitivity analysis

	S1	**S2**	**S3**	**S4**	**S5**	**S6**
CSF1	0.663215	0.722314	0.690055	0.75292	0.670094	0.486565
CSF2	0.752646	0.618035	0.810294	0.808927	0.799038	0.71311
CSF3	0.952815	0.936117	0.954562	0.954236	0.951881	0.96553
CSF4	0.971442	0.976556	0.979342	0.967762	0.966092	0.967762
CSF5	0.971445	0.976558	0.95675	0.967765	0.978114	0.979188
CSF6	0.952787	0.948542	0.943418	0.965515	0.963747	0.943032
CSF7	0.905633	0.922312	0.93144	0.919841	0.845452	0.908875
CSF8	0.837141	0.865727	0.813715	0.869723	0.778467	0.859049
CSF9	0.271912	0.338912	0.197742	0.199212	0.209337	0.414965
CSF10	0.659412	0.70796	0.687298	0.749953	0.527945	0.623128
CSF11	0.742357	0.681822	0.790286	0.750841	0.737068	0.744616
CSF12	0.917234	0.931639	0.917841	0.928146	0.924521	0.887004
CSF13	0.952775	0.948531	0.943408	0.954208	0.96374	0.954208
CSF14	0.952759	0.948517	0.943394	0.9655	0.951837	0.954197
CSF15	0.912585	0.915644	0.914491	0.935916	0.871136	0.924854

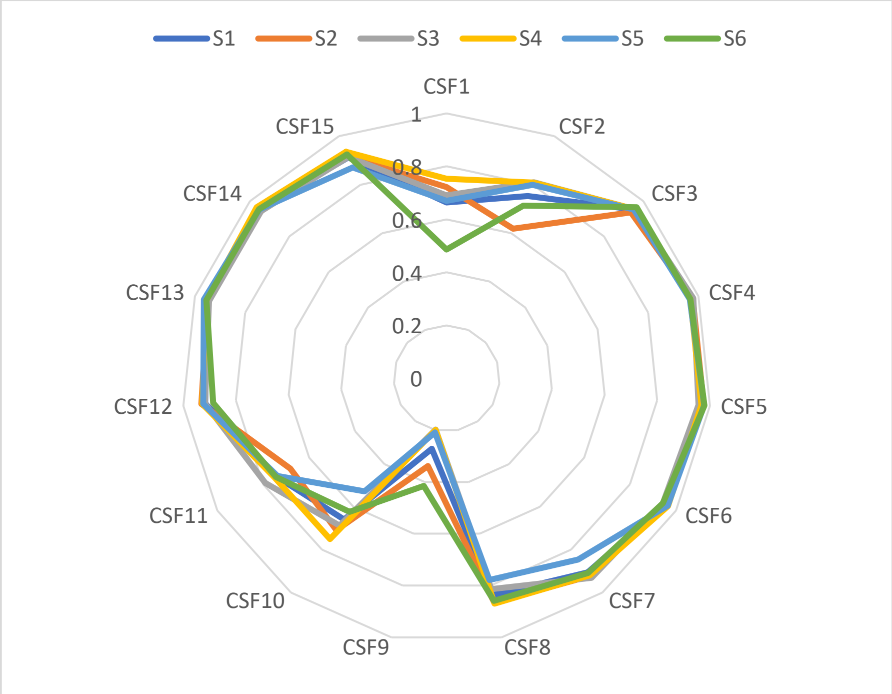

Figure 6.2: Sensitivity Analysis

6.6 Managerial Implications

The presented results provided insights to the practitioners, industry managers to successfully adopt AMTs in industries. It is seen that Strategic planning for implementing AMTs ranks first position among the identified CSFs. There can be initial hurdles faced in the pathway of AMTs adoption. Strategic planning helps to make the things systematic and develop the prospective plans to tackle the anticipated risks. Moreover, strategic planning helps to align the organizational activities to prospective vision and mission in effective manner. Also, it helps in optimum utilization of resources, effective managerial decision making, long-term sustainability and precisely measuring organizational performance. Top management commitment for AMTs implementation plays an instrumental role for adopting AMTs and ranks second. It helps to develop strategic initiatives which aligns best with organizational objectives. Moreover, it helps to foster positive organizational culture where the employees have the freedom to express their innovative ideas for the upliftment of the organization.

Moreover, it results in adopting change management strategies effectively to overcome employee resistance and make employees more engaged, and informed. Top management commitment also facilitates strong partnerships and collaborations which ultimately helps to get creative ideas, facilitates learning, that eventually helps to successfully adopt AMTs.

6.7 Concluding Remarks

Examining the roles of CSF in the success of AMTs implementation plays a pivotal role. On the one hand, the framework may be used to understand the most important components to consider while implementing AMTs, while on the other hand, it will save the time, efforts and resources of the industry protectors and provides a great scope of improvement for developing countries. Businesses may increase their flexibility and speed of reaction in order to provide a better response to their consumers with less variability and much better products with less waste, which is good for the environment. Research on the essential success aspects of AMTs can help the managers better understand the primary issues that arise while deploying AMTs in industries, as well as the best methods for overcoming such obstacles.

Implementation of Advanced Manufacturing Technologies are subjected to various challenges in manufacturing industries specifically for industries. By means of implementing AMTs, the industries can improve their ranking and market reputation by providing quality products to the customers. It is found through extant literature that customer's demands are highly dynamic. In order to thrive in competitive market scenario, it is very essential for the industries to upgrade themselves and adopt AMTs. Also, for long term sustainability, industries must realign themselves as per changing demand patterns of the customers. AMTs facilitates the industry to adopt flexible manufacturing practices and incorporate these changes in negligible amount of time. The next chapter analysed the challenges of implementing AMT using SAP-LAP approach.

Chapter-7: Analysing the challenges in adoption of advanced manufacturing technologies: Case studies

7.1 Introduction

Vacillated customer demands for high quality products at reasonable cost in minimum span of time forced the industry to adopt latest tools and have state-of-art facilities in the manufacturing system. After three marked revolutionary stages in the past, manufacturing era is going thorough fourth industrial revolution at present, which has been found to give magnificent benefits in terms of financial and operations performance. It entails use of technologies like Internet of Things (IoT), Cyber Physical System (CPS), Cloud computing, Big data analytics, Augmented reality etc. In this chapter, barriers of AMTs have been identified through extensive literature review and in discussion with industrial experts. SAP-LAP approach is used to analyse the issues. The results will help the industrial managers to understand the different kinds of challenges and their relative importance so that necessary steps can be taken to overcome these barriers. The research results will guide the industries to understand the concerns and adopt proper strategies for effective implementation of advanced manufacturing technologies.

Demand for high quality of products at reasonable cost by customers has forced the industries to adopt state-of-art technologies like robotics, automation, 3D printing, artificial intelligence, machine learning etc.in order to cope up with the changing market conditions (Mosterman and Zander, 2016; Hwang et al, 2017). The industries which have kept themselves up to date, stayed competitive in the market, other industries lag. The industrial processes need to be restructured, redesigned, and reoriented in order to survive in the marketplace. Sung (2018) discussed that producing high quality products to the customers at economical prices is the key to success in modern industry scenario. Till year 2011, manufacturing era has gone through three marked revolutionary phases with significant improvement in technologies. In the last one decade, the concept of AMTs was created by Europe in collaboration with industries and universities. It is analysed as pivotal strategy by researchers and industrialists to meet the customized customer requirements, reducing wastages, achieving sustainability, attainment of circular economy and achieving operational excellence etc. Industrial Internet of Things (IIoT) or digital manufacturing. Many researchers all over the globe have exemplified the concepts involved in AMT and eradicated the woolliness. Yin et al. (2018), described how industrial revolutions emerged from industry 2.0 to industry 4.0. The vitality of Industry 4.0 is getting to widen exponentially since its inception. According to Porter and Happlemann (2014); Liao et al. (2017), in the present scenario, AMTs entails use of technologies like Cyber Physical System (CPS), Cloud Computing, Big Data Analytics, Augmented Reality, Virtual Reality etc. Frank et al. (2019) developed the conceptual framework of implementation patterns of Industry 4.0 in manufacturing industries. Base technologies were identified to be IoT, big data analytics, cloud computing, cyber physical systems, machine learning etc. The authors also reported in his study about front end technologies like digital supply chain, smart working, smart manufacturing, and smart product.

The results obtained in Chapter-3, 4 and 5 are validated using two case studies which are discussed in this chapter. After going through existing research studies available, it is found that literature related to adopting advanced manufacturing technologies in context of emerging economies like India is limited. As discussed in the previous chapters, there are fewer case studies available in context of AMT adoption like Industry 4.0. Therefore, the presented study provides a platform to analyze the challenges using case-based research. Therefore, to fill the research gap, the following research questions were formulated:

a. What are the major challenges for adoption of advanced manufacturing technologies?

b. How the research results can be beneficial for industrialists, practitioners, researchers and policymakers?
c. How can the adoption of advanced manufacturing technologies help the industries to have competitive edge over other players in the dynamic market landscape?

7.2 Literature Review

Industrialists, Managers and researchers all around the world have started realizing the potential benefits by implementation of Industry 4.0 (Buchi et al, 2020). Industry 4.0 technologies enable the operator in remote monitoring and control of equipment in real time. Researchers all over the world are working on various aspects of Industry 4.0 so that it can be implemented effectively and efficiently. The challenges and barriers of AMTs have been found out by distinct researchers at various locations of world. Muller et al (2018) has conducted his research in Germany to identify challenges encountered while planning for AMTs implementation. These were found to be intense competition and feasibility, industrial fitness for adopting AMTs, required skill sets of employees. Horvath and Szabo (2019) found out that the barriers of AMTs implementation in Hungary are lack of financial resources, lack of standardization, cyber-security issues, technology and processes integration issues, lack of competencies, resistance to change, human resources issues etc. Almost same results has been analysed by Nagy et al. (2018) in Hungary; lack of clear comprehension of digital strategy in manufacturing and lack of top management commitment were found to be most significant barriers. Nevertheless, manufacturing industries are striving hard to overcome these obstacles and implement AMTs in manufacturing system. In Romania, Turkes et al. (2019) determined that dedication, huge investment in human-capital, skilled work force was found to be most influencing factors while planning AMTs. By the same token, in other parts of world, research studies were carried out like in India (Kamble et al., 2018); Europe (Stentoft et al., 2019); Sweden (Tomic, 2017); Inter-continental study (Italy, Austria, Thialand and USA; Orzes et al., 2018).Turkes et al. (2019) have analysed the scenario of implementing AMTs in Romania. It was found that 84 % of industry Managers are aware of AMTs concept.

Although, AMTs complies with automation of manufacturing plant, it does not mean that human operators will be no more needed on shop floor. Human factor has always been indispensable factors in manufacturing industries. The delusion that human factors will not be required was also there before the introduction of automation technologies like robotics, Computer Numerical Control (CNC) machines etc. in the market. The data regarding creation of employment diversity after implementing automation technologies revealed the positive impact on society. Many researchers argued whether human workforce will be required or eliminated in implementation of Industry 4.0.

There is general notion that industry 4.0 will eliminate human operators and each and every activity will be automatic without human intervention. In actual practice, it is going to transform role of operators, from active performer to passive observer. Rather, it implies change in skills sets and dexterity of operators. Laudante (2017), with the advancements of automation and allied technologies, human skills requirements are changing i.e. physical to cognitive. Longo et al. (2017), explained smart operators are required in smooth functioning and operation of AMTs. Sophos-MS digital interface, which act as knowledge management system was designed to guide the operators. Romero et al. (2016) discussed various evolution of operator generations i.e. operator 1.0 to operator 4.0. Need of cognitive capabilities of smart operators in organizing and establishing shopfloors in compliance of AMT standards was realized. To accomplish this objective, cognitive capabilities of operators like diagnosing and planning the processes involved in manufacturing, industrial design, developing machine learning algorithms, decision making and supervision are of prime importance. Gasova et al. (2017) discussed advanced ergonomics tools applications in Industry 4.0. Ceit Ergonomics Analysis Application (Ceit) was exemplified which reduces potential risks of operators and ensure their safety. Sari et al. (2019), feasibility analysis of AMTs in automotive maintenance system was analysed; which enables the driver to get warning message before system breakdown occurs.

Baeno et al. (2017) suggested the concept of learning factory for AMTs implementation. Martinsen (2020) explained Learning factory as a full-fledge simulator of all manufacturing activities like conveyor system, robots, machining system, automatic storage and retrieval system etc. They found learning factory as the efficient and effective tool for developing pragmatic knowledge experience just like in case of real manufacturing scenario.

Romero et al. (2016) described human centricity as central component of AMTs. Although implementation of AMTs will lead to mitigate the importance of physical ergonomics but cognitive ergonomics plays very prominent role in designing and successfully implementing these technologies in the manufacturing system. Since, the concept of AMTs involves complex operations like developing algorithms for big data analytics, designing machine to machine communication, virtual ergonomics analysis; requirement of highly skilled staff is needed. Kaasinen et al. (2020) discussed empowering the operator 4.0 with adaptive work processes and collaborative job design. The manufacturing system needs to be designed keeping in mind the cognitive ergonomics aspects. It is required to be designed in consideration of operator's concordance i.e. putting less cognitive load on operators. Also, tasks are required to be given as per operator's skills and associated cognitive load involved in it. For instance, if complex task is assigned to low skilled operator, it will result in high cognitive load. Similarly, if high skilled staff is assigned with low cognitive task, the operator will feel bored some. Since a huge investment is required to implement AMTs incumbent technologies, it become necessitate for the industries to undergo feasibility analysis before starting its implementation phase.

Advancements in industrial technologies ushering the operators to sharpen their cognitive skills such as information processing capabilities, data analytics, decision making capability in complexity of operations involved in automation. The Industrialists have started realizing the potential benefits of implementing AMTs in their manufacturing system. But there are some issues while planning for AMTs. What are the skills-sets required for implementing AMTs? What is the probability of availability of skilled staff to operate Industry 4.0 plant? Is the existing staff are passionate to learn AMTs core technologies? Can the machines currently used be retrofitted to make it compatible with AMTs standards? How much investment is needed to implement AMTs? What is the return of Investment or tentative financial performance after implementing AMTs? To answer some of these questions, we consider human resource issues in this section. There is plethora of research available in context of core technologies used in AMTs, Sustainability analysis, Potential benefits of AMTs etc. However, very less literature is available dealing with cognitive skills requirements in AMTs.

Table 7. 1: Some Studies from various countries for challenges in implementation of Industry 4.0

Name of Author	**Investigated country**	**Key findings**
Muller et al. (2018)	Germany	The challenges were found to be intense competition and feasibility, industrial fitness for adopting AMTstechnologies, required skill sets of employees. Also, the opportunities were found to be strategic advantages, manufacturing excellence, conserving the environment.
Veile et al. (2019)	Germany	Availability of financial resources, integrating employees in to AMTs implementation, coordinating interdisciplinary teams, proper planning of activities, relationship among stakeholders,

		effective data handling and teamwork were found to be crucial aspects.
Horvath and Szabo(2019)	Hungary	The barriers were found to be lack of financial resources, lack of standardization, cyber-security issues, Technology and processes Integration issues, Lack of competencies, Resistance to change, Human resources issues etc.
Nagy et al. (2018)	Hungary	Lack of clear comprehension of digital strategy in manufacturing and lack of top management commitment were found to be most significant barriers. Next important barriers were found to be data and privacy issues and inability to estimate economic benefits by implementation of AMTs
Turkes et al. (2019)	Romania	Dedication, huge investment in human-capital, high investment were found to be most influencing factors while planning AMTs. Romanian's manager's views were taken to discuss the importance of associated technologies; these were found to be horizontal and vertical integration, big data analytics, autonomous robots, IoT and security and privacy issues.
Kamble et al. (2018)	India	Kamble et al (2018), discussed the barriers in adoption of AMTs in manufacturing industries. Employee disruptions, inability to comprehend AMTs potential benefits, lack of funds, lack of skilled manpower etc.
Dalenogare et al. (2018)	Brazil	The benefits of implementation of Industry 4.0 were enumerated as product customization, efficient utilization of resources, enhanced quality of products, better energy

		efficiency, minimization of operating costs, better and real time decision making, enhanced sustainability of manufacturing processes, reduction in takt time, improved safety of workers.
Orzes et al. (2018)	Inter-continental study (Italy, Austria, Thialand and USA)	High investments, lack of top management commitment, lack of skilled manpower, data and security concerns, requirement of digital business model, lack of enhanced coordination etc. were found to be most significant barriers.
Stentoft et al. (2019)	Europe	Lack of standard metrics, lack of understanding of importance of AMTs, lack of data security concerns, lack of educated and qualified employees, lack of financial resources, lack of workforce readiness etc. were found to be the barriers.
Tomic (2017)	Sweden	Data security and management, resistance to change, risk assessment and implementation issues were found to be key barriers.
Sung et al. (2018)	Korea	Cyber-security issues, fear of job loss due to automation, lack of required skill-sets, resistance to change by stakeholders, IT hitches, seam less integration of equipment were found to be major obstacles in implementation of AMTs.
Raj et al. (2019)	Inter-country perspective (India and France)	The barriers were found to be high initial investment, lack of clear comprehension of AMTs potential benefits, value chain integration issues, security and privacy issues, lack of standardization, rules and policies, employee disruption, lack

		of enhanced skill sets etc. Grey DEMATEL technique was applied; lack of digital strategy and scarcity of resources were identified to be key barriers.
Frank et al. (2019)	Brazil	Frank et al. (2019) developed the conceptual framework of implementation patterns of AMTs in manufacturing industries. Base technologies were identified to be IoT, big data analytics, cloud computing, cyber physical systems, machine learning etc. He also reported in his study about front end technologies like digital supply chain, smart working, smart manufacturing and smart product.
Tortorella et al. (2020)	Brazil	Empirical model was testing to determine relationship between implementation of AMTs and operational excellence; taking organizational learning as mediating link in three models: Individual, team and organizational. Industry learning capabilities was found to positively affect the relationship among AMTs implementation and operational excellence. Furthermore, it was explored that AMTs technologies assist in creation, retention and dissemination of skills and expertise in the organization.

Kagermann et al. (2013) Industrial Internet of Things (IIoT) or AMTs is transforming organization's strategies, working principles, working models, supply chain network practices, product/processes, operator skills, equipment handling and control etc. Major business-processes reengineering has been depicted in figure 5.1. In manufacturing plant based on cyber-physical system, the physical load will be reduced considerably, however the operators will be required to deal with the algorithms, data obtained from various machines and equipment, so cognitive computing skills is of utmost importance (Petrillo et al., 2018). The conventional supply chain management have to transform into digital supply chain or supply chain 4.0 which is able to analyse the customer demands in real time and accordingly changes in existing product design, sequence of operations can be made at that moment without wasting time and customized products can be made available to customers in minimum span of time. Lorenz et al. (2015) explained that implementation of smart supply chain will reduce the number of employees in operations planning but demand for coordinators controlling flows across supply chain will be increased. Smart operators having high cognitive skills, information processing and data analytics are required; need of physical ergonomics is gradually changing into cognitive ergonomics. Culot et al. (2020) described the core technologies of AMTs in to four clusters i.e. physical/ digital interface based on level of network connectivity and technological elements. For instance, physical digital edge technologies, network-based technologies, physical digital process technologies and data-analytics technologies. Technologies like 3D printing and advanced robotics were placed under low level of connectivity of network and high percentage of hardware components. By the same token, ML, AI, big data analytics and simulation and modelling comes under high percentage of software component and lower level of connectivity. In AMTs based manufacturing system, real time remote monitoring and control of machines is done by operators. The machines are made self-aware to diagnose any problems, issues or defects using algorithms. Also, real time predictive maintenance will be made possible so as to eliminate manufacturing down time. Petrillo et al. (2018) discussed that high-tech advanced simulation tools are capable to analyse business processes, manufacturing system in real time. Machado et al. (2020) explained that AR based environment gives wonderful results in improving work and maintenance actions and in virtual trainings.

Acquisition of digital skills by operators, scalability and availability of funds were found to be major challenges for implementation of AMTs. Dalenogare et al. (2018) described operational and enhanced product design benefits of implementing AMTs.

Fareri et al. (2020) explained that soft skills are highly desirable and form the basis of digital manufacturing. Longo et al. (2017) discussed human focused approach to increase operator's competences and capabilities within future of manufacturing. Operators needs to be trained with latest tools and techniques like IoT, Artificial intelligence, CPS, big data analytics etc.to convert the dream of implementation of AMTs in to reality. Also, Stormer et al. (2014), Akkari et al. (2019) mentioned the significance of cognitive ergonomics in Industry 4.0 context. The operators are required to work in multidimensional areas and must be having strong intellectual skills in dealing with complexities of industrial design. Akkari et al. (2019) also discussed that the operators are required to have perseverance, enhanced communication skills, virtual capabilities. Kazancoglu and Ozkan-Ozen (2018) explained role of smart operators in fourth industrial revolution from perspective of operations management. 11 criteria's of smart operators are defined as flexibility to changing working environment, interdisciplinary learning, strong inclination towards information and communication technologies, passion towards learning new and advanced technologies, capability of solving complex problems, knowledge of IT security and privacy issues etc. These 11 criteria' s were analyzed using fuzzy Decision making trial and evaluation laboratory (DEMATEL) and divided in to cause and effect categories depending on the prominence calculated.

The same results were also analysed by Turkes et al. (2019), the six factors while implementing AMTs in SMEs in Romania were found to be lack of clear comprehension of AMTs, lack of standard rules and regulations, lack of knowledge of strategic importance of AMTs, reduced human resources, emphasis on education on smart technologies, more focus on operation. Tomic (2017) discussed the potential advantages by implementing AMTs are high quality of products, optimum utilization of resources, enhanced customization and customer satisfaction, prevention/prediction of failures. All these mentioned advantages help the industries to maximize the production and sales which eventually results in profit maximization.

Tortorella et al. (2018) discussed mediating the role of employee engagement on determining the relationship among industry 4.0 implementation on operational excellence. The study was done in 147 Brazilian industries, it was estimated that employee engagement support implementation of industry 4.0 effectively which give rise to some barriers in context of enhancing the skill sets and education of employees. The feasibility analysis embraces the things like compatibility of existing staff towards adoption of required advanced methodologies, retrofitting of machines to make it work in compliance of AMTs standards, capital required and finance availability, design of manufacturing system, digital supply chain etc. Erol et al. (2016) explained awkward working posture will be captured by motion capture system which in turn will intimate the operator to correct the posture with the help of digital assistance system. Jiao et al. (2020) analysed human-automation interaction cognition using augmented human-CPS system in smart manufacturing environment.

The knowledge gaps identified after going through Scholarly literature clarifies that studies pertaining to assess challenges of advanced manufacturing technologies are inadequate in Indian context. Hence, the research questions were framed as follows:

a. To identify the challenges of advance manufacturing technologies adoption.

b. To assess how the adoption of advanced manufacturing technologies can result in organizational excellence.

Table 7. 2: Challenges of AMTs implementation

S.No	Advanced Manufacturing Challenges	References
1	Less support from top management and issues related to commitment	Kamble et al. (2018), Luthra and Mangla (2018)
2	Lack of planning towards effective vision and strategy formulation	Luthra and Mangla (2018), Raj et al. (2019)
3	Employee resistance towards digitalization	Kamble et al. (2018), Longo et al. (2017)
4	Lack of standards and operating protocols	Luthra and Mangla (2018), Machado et al. (2020)
5	Lack of IT infrastructure	Kamble et al. (2018)
6	Lack of competencies in adopting digital business models	Luthra and Mangla (2018), Frank et al. (2019)
7	Lack of technological integration	Frank et al. (2019), Abdul-Hamid et al. (2020)
8	Lack of stakeholders collaboration	Machado et al. (2020)
9	Cyber-security concerns	Frank et al. (2019), Abdul-Hamid et al. (2020)
10	Shortage of funds	Luthra and Mangla (2018), Machado et al. (2020)
11	Lack of adequate governmental policies and support	Machado et al. (2020)
12	Unclearity of financial gains in investing advanced manufacturing	Frank et al. (2019), Abdul-Hamid et al. (2020)
13	Lack of research ecosystem in industries	Machado et al. (2020)

7.3 Research Methodology

In the presented research, a leading manufacturing industry was considered to assess the challenges regarding adoption of advanced manufacturing technologies. Past literature shows that the researchers have used one or bunch of case studies are establishments of research results. Also, it was reported that analysing single case study provides a deeper and novel analysis as compared to comparison analysis (Gupta and Singh, 2020). Also, case study can assess the real-life problems in more effective manner as it tries to analyse and create the principle theories associated with it. For instance, Kamble et al. (2018) stated the challenges in adopting advanced manufacturing technologies includes lack of standard operating protocols, cyber-security issues, lack of required proficiency and experience, financial constraints, lack of clear understanding of advanced manufacturing technologies adoption. These research results were found to be similar with Raj et al. (2019).

Table 7. 3: Steps Involved in Research

Steps	**Description**
Objectives Stating the Research Objectives	To identify and analyse challenges of advanced manufacturing technologies adoption. The case study aims to give the answers to following research inquiries: • What are the key challenges of advanced manufacturing technology adoption? • What are the key technologies emerging in dynamic market landscape? • How adopting advanced manufacturing technologies help to achieve sustainability? • What sorts of changes are required in the organization for effective implementation of advanced manufacturing technologies? • How can the adoption of advanced manufacturing technologies help to achieve organizational excellence?

Selection of a case	The case industry is reputed automobile manufacturing firm in India. The industry shown keen interest in adopting advanced manufacturing technologies. The current case industry is named as Alpha Ltd., located in Gurugram, India. The industry had legacy of 32 years.
Research Planning	SAP-LAP framework is used for case analysis. All the required data is gathered to assess situational players that affect adoption of advanced manufacturing technologies. This is followed by exploration of key decision-makers and processes in the industry. This is followed by LAP analysis to identify the areas of improvements. On the basis of results obtained, some actions are suggested.
Developing research instruments	Both primary as well as secondary method was used for gathering data. Semi-structure interviews were conducted to collect the primary data. Also, e-mails and Google forms were used to gather information for conducting SAP-LAP analysis.
Data Collection	Primary data was collected by face-to-face interaction with employees of case industry. The secondary data was collected from websites, published industrial reports etc.
Data Analysis	The gathered data and information is analysed using SAP-LAP framework.

Source: Eisenhardt (1989)

As stated in research questions and objectives are stated earlier, the case majorly focuses on adoption of advanced manufacturing technology. The top management, high-ranked professionals were consulted to collect the primary data. Multiple visits were made to the manufacturing plant depending on the availability of the personnel. The research outcomes can be highly beneficial to develop creative and innovative solution for advance manufacturing technology adoption. Looking at all these perspectives, deep insightful study was carried out and is represented in the present study.

7.4 SAP-LAP Framework

SAP-LAP framework is used to analyse the presented case study. Sushil (1997) stated that it is flexible, innovative, creative and qualitative tool to assess the case study. In the current study, SAP LAP analysis framework is used to assess the challenges of advance manufacturing technologies adoption in the considered case industry. The data and information is gathered as per compliance of SAP-LAP framework. This framework provides the decision makers a platform for critical thinking and problem solving. SAP stands for “Situation”, “Actor” and “Process”. Situation implies the condition of the system to be handled. “Actor” represent the people, or group of people handling a specific situation. Process indicates the conversion of existing ways of performing a task (Sushil, 1997). Furthermore, this is followed by LAP analysis. LAP states “Learning”, “Action” and “Performance”. SAP-LAP framework is used by various researchers in different applications. The framework is very well suited in providing flexibility and assesses dynamic market scenarios. Garg and Deshmukh (2010) analysed challenges in flexibility attainment in maintenance domain to prevent breakdown and continuous production. Chand et al. (2018) analysed supply chain intricacy variables in mining industries for efficient supply chain management and improve organizational performance. Chavan et al. (2019) applied this approach in understanding prospective bottlenecks to infrastructure and urbanization. The results were directly related with achieving sustainable development goals. Mishra et al. (2022) analysed digital transformation and disruptive innovations to enhance innovation potential

7.4.1 Background of Case Industry

Alpha Ltd. (changed name as per the affirmation with case industry) is pioneered in manufacturing trucks, buses and light vehicles. It is the 2nd largest manufacturer of commercial vehicles in India, the 4th largest manufacturer of buses in the world, and 19th largest manufacturers of trucks. The industry was also rewarded as 34^{th} best brand in India. A US $4.5 billion industry had footprints that spread across 50 countries across the world. The case industry is recognized in producing commercial vehicles, therefore established the benchmarks and standards. The industry has ISO/TS 16949 certification and was the first to receive BS-IV. The industry also has on board diagnostic (OBD-II) certification. The industry made use of various advanced technologies including selective catalytic reduction (SCR) and intelligent exhaust gas recirculation (IEGR). The industry was also rewarded with Deming Quality award for par excellence. The company is driven by digital transformations and innovative practices to satisfy its customers and survive in the global market.

The top management and senior professionals showed great interest in adopting advance manufacturing technologies. Around 55 to 65 % management officials were able to recognize the need of digital transformations and continuous up gradation of processes. It is found to be directly linked with achieving sustainability. The management needs to be explore the innovative ways to handle the challenges in the pathway of advance manufacturing technologies adoption.

7.4.2 SAP-LAP Analysis of Alpha Industry-Case Study-I

SAP-LAP analysis framework was used to analyse the understanding of case industry towards advanced manufacturing technology adoption. The current situation was assessed using SWOT analysis. The situations were explored, learning was framed and accordingly actions were suggested. Eventually, the impact of actions on performance of case industry was assessed in the case industry.

Situation: The situation explains the present condition of the firm towards advanced manufacturing technologies adoption. The assessment of these mentioned variables provides a clear understanding to the case industry about the lacunas and suggested strategies for effective handling of encountered challenges. The results of SWOT analysis are shown in Table 7.4.

The outcomes of SWOT analysis of Alpha case industry are summarized as follows:

a. The increased competitive pressure and changing customer demands led the manufacturing industries to adopt advanced tools and techniques.
b. Customer demands for extreme quality products and services.
c. Industries are required to produce high quality products and that too at optimum price.
d. Low adoption of advanced manufacturing technologies
e. The purpose of achieving sustainable development goals
f. Use of performance measurement rubrics for analysing readiness towards advanced manufacturing technologies
g. Selection of strategic tools for effective handling of anticipated issues.

Actors: It signifies the decision makers involved in taking strategic judgments related to adoption of advanced manufacturing technologies. The case industry facilitates the participation of all stakeholders in continuous improvement activity. The following top management and senior professionals were contacted to collect the data and information using semi-structured interviews.

a. Top management including CEO, board members which participates actively in policy formulation and taking pivotal decisions
b. Stakeholders including suppliers, customers, employees.

Table 7. 4: SWOT Analysis of Alpha Industry

Strengths	**Weakness**
• Reputed in automobile sector in developing economy • Agile and Flexible • Legacy of 72 years • 600+ highly qualified workforce • Using advanced technologies like Robotics, SCADA in production system • Machine vision enabled workstations • Large manufacturing portfolio	• Less knowledge about smart technologies • Lack of conducting training and educational programs • Reduced market share • Lack of research initiatives
Opportunities	**Threats**
• Use of Environmental, Social and Governance for advanced manufacturing technologies • Focus on lean-automation • Enhancement in overall organizational performance	• Globalized competitive pressure • Production of components at reduced costs using different materials from other manufacturers

Processes: The key processes involved in manufacturing of case industry include design, assembly, quality inspection and control, logistics and supply chain management. The other supportive departments being human resources, finance, marketing, maintenance, inventory control, research and development etc. Various research studies (Kamble et al., 2018; Frank et al., 2019) discussed that adopting advanced manufacturing technologies is significantly correlated with achieving sustainability, reducing the wastages and enhanced organizational effectiveness. The description of processes identified in the case industry is described as follows:

a. Procurement of high-quality items from listed vendors
b. Robotic welding on the assembly line, therefore eliminating the repetitive work.
c. Machine vision-based manufacturing equipment's to monitor and control quality issues.
d. ERP based solutions for effective handling of processes across different functional areas.
e. Effective fleet management system to ensure timely delivery of the products across the supply chain.

Learning

The Alpha Industries has excellent record of producing high end products and supportive organizational structure. The industry is renowned worldwide but is lacking in adoption of advanced manufacturing technologies. However, the industry is well known of the fact that governmental pressure certainly will force the industry to adopt sustainability. The learning aspects help the industry to understand the loopholes found in current situation, so that necessary steps can be taken accordingly. The top officials showed their keen enthusiasm and more inclination towards learning new technologies. These efforts will directly impact on quality of products and ultimately customer satisfaction level.

a. Proper strategic plans need to be developed for hassle free implementation of advanced manufacturing technologies.
b. More focus on research and development needs to be given so that innovative and efficient solutions can be explored.

c. Training and educational programs can be organized to combat employee resistance to change.
d. Amenable organizational culture works a lot in bringing the creative and innovative to the upfront and analyse it through group discussions.

Actions: The SAP framework provides insights to the managers about the required changes for adopting cutting edge technologies. Based on learning, the industry can initiate change management and design thinking programs as an effective technology management tool. The following path-breaking findings were analysed using SAP-LAP framework:

a. Employees can be trained sufficiently so that they are able to deal with advanced technologies.
b. Retrofitting of equipment can be initiated so that already existing set-ups can be used
c. Awareness of AMTs implementation can be spread among top management officials, employees and supporting staff.
d. The employees can be motivated to attend workshops, seminars and conferences so that research ideas of AMTs implementation can be discussed for more clarity of technologies.
e. Government can start some technical knowledge centres so as to help the industrialists regarding successful implementation of AMTs.

Performance:

The performance parameter is evaluated once the advanced manufacturing technologies are adopted by Alpha Ltd. SAP-LAP framework facilitates to analyse the performance metrics based on actions recommended. A team of senior officials was consulted to assess the outcomes. Regular visits were made to come to a common concordance of the experts. Based on the analysis, it was found that adopting advance manufacturing technologies have a profound impact on productivity and profitability of case industry. Although, initial cost of implementation may be high, but payback period is small.

- Quality of the products and efficiency can be increased enormously with adoption of advanced manufacturing technologies.
- Supply chain effectiveness can be enhanced through transparency and traceability leading to more customer satisfaction.
- The wastages can be reduced exponentially or recycled which directly contributes towards achieving circular economy and meeting sustainable development goals.
- The manufacturing data can be traced in real-time enabling the managers in effective decision making.
- Sales forecasting can be done more precisely leading to increased organizational effectiveness.
- Mass customization can be achieved using additive manufacturing and advanced tools resulting in increasing customer satisfaction.
- Human-cyber physical system and augmented reality enabled devices lead to more safety of employees.
- Use of AI and machine learning tools can reduce lead time and energy requirements.
- Predictive maintenance tools can better predict maintenance requirement, prevent breakdowns and energy consumption.

An automobile manufacturing industry ABC located at NCR of India was considered to analyze the SAP-LAP linkages. The company falls under original equipment manufacturer category having enriched experience of 35 years in providing two wheelers. It is pioneered in providing more than 20 varieties of products. The turnover of industry is $5 billion, and have 8000 employees. The industry is having highly dedicated, advanced and flexible manufacturing system and aspires to provide highly quality products and services to the customers. Also, the industry believes in continuous improvement policy with implementation of new technology and innovative practices.

7.4.3 SAP-LAP Analysis of ABC Ltd- Case Study- 2

SAP-LAP analysis provides a platform to analyze strongly the case studies (Sushil, 1997, 2001). The various components are explained as follows:

1. Situation:- Situation is represented by management of existing scenario. As we know technologies are helpful for manager to monitor and optimize the resource consumption but their absence cannot give the desired results. In the case company ABC considered, the industry considered was using energy intensive processes and equipment. The industry was not able to meet the delivery of the products on time. Lack of availability of skilled manpower was impediment to adoption of advanced manufacturing technologies. Also, the industry was not having sufficient funds and was unable to afford high-cost advanced equipment. Furthermore, the top management officials were found to be unaware of adopting advanced manufacturing technologies benefits. The utilization of advanced technologies such as cloud computing and CPS is highly essential for enhancing the quality of products and optimum utilization of resources. The material circularity and energy can be supported by The Industry 4.0 technologies (De Sousa Jabbour et al., 2018). Also, Industry 4.0 technologies can enable the companies to collect real-time information of consumers' behaviour.

2. Actor: It signifies the variables to answer and handle the circumstances in SAP-LAP. In advanced manufacturing technologies adoption, "Actors" can be either Internal or external. In ABC firm considered, the external actors involve government policies and recommendations, while the internal actors are organizational culture, employee commitment, top management involvement. Higher authorities must understand and comprehend the strategic advantages by implementing advanced manufacturing technologies. Also, scholarly literature reveals that advanced manufacturing technologies helps the industries to achieve competitive edge. Also, the government must facilitate the enforcement policy and initiate financial benefits to the industries.

3. Process:- The process includes how to deal with the situation? In ABC firm considered, the situation can be deal with sustainable manufacturing chains. Employees of the industry considered are lack in technical skills. So, training and educational programs are highly required to develop required skill sets among employees. Also, employees were found to be reluctant to change as per ongoing latest technological trends. But employee need to be motivated and passionate so that advanced manufacturing technologies can be implemented with relative ease. Furthermore, research and development activities were found to provide cost effective viable solutions within reduced time. During infrastructure for adopting advanced manufacturing technologies, top managers share their experience of uncertainty. Advanced manufacturing technologies is found to be helpful in resolving all the above discussed problems.

4. Learning:-The learning at ABC industry includes the clear understanding the challenges faced during the implementation of advanced manufacturing technologies. Focus towards lean automation will help in providing cost-effective solutions. Efforts by skilled manpower must be made in retrofitting of equipment so that seamless integration of equipment can be established. Also, Government should initiate the policies towards advanced manufacturing technologies implementation. Moreover, business process reengineering is imperative for effective and efficient utilization of resources. The enforcement of CE developmental model in Industry 4.0 specially in developing countries like China is quite helpful in regulation of resource depletion and degradation (Bressanelli et al., 2018).

5. Action: It represents capabilities of ABC company to adopt advanced manufacturing technologies.The learning is responsible for arise of actions i.e. where and when to be implemented. (Sushil, 2017). The CE business practice transformation takes place through advanced manufacturing technologies. A study by Bressanelli et al. (2018) focused on advanced manufacturing technologies functionalities which include product design betterment, fulfilling customer requirements, real-time monitoring of processes, technical support, maintenance plan, optimum utilization of resources, upgradation of product, research, and development activities. The sensors and robotics usage will enhance waste sorting and recycling efficiency. IoT and CPS can facilitate decision making through the real-time availability of data and improve the optimal use of resources which reduce wastage by identification and mitigation of possible failures. Also, other advanced techniques like Additive manufacturing, 3D printing in the context of Circular economy business models results in effective reutilization of resources.

6. Performance: - Performance attains the achievement of final objective. The performance objectives of adopting advanced manufacturing technologies in ABC firm results in increased sustainability by the circularity of material enhancement, eco-efficiency by overall accomplishment. Moreover, as a result, the industry can attain flexible production, optimum utilization of resources, reduced unit cost, wastages, increased market share and operational efficiency. Also, it facilitates in achieving Circular Economy, which is a fusion of two interwoven designs: - closed-loop economy and “design to re-design” thinking (Murray et al., 2017). Table 7.5 discussed SAP-LAP analysis of AMTs.

Table 7. 5: SAP-LAP framework of ABC industry for adopting advanced manufacturing technologies

Stage	Component	Notation	Concerned Issues
SAP	Situation	S1	Consumption of excessive energy in traditional manufacturing system
		S2	Excessive delays and lead time
		S3	Lack of skilled manpower
		S4	Unawareness about potential benefits of adopting AMTs
		S5	Scarcity of funds
	Actor	A1	Top management support
		A2	Government rules and regulations
		A3	Training and Educational Programs
		A4	Employee commitment
	Process	P1	Focus on research and development activities
		P2	Employee's passion to adopt advanced manufacturing technologies
		P3	Data Insights
		P4	Reduced cost of manufacturing
	Learning	L1	Development of lean automation solution for cost effective solutions
		L2	Seamless integration of equipment
		L3	Decentralization
		L4	Business Process Reengineering
	Action	A1	End-to-end connectivity
		A2	Optimum Utilization of Resources
		A3	Real time monitoring and control of operations
	Performance	PF1	Flexible production
		PF2	Enhanced Quality of Products
		PF3	Increased Efficiency and Sales
		PF4	Increased Market Share
		PF5	Improved Operational Excellence
		PF6	Reduced Wastages

7.5 Concluding Remarks

India is at nascent stage of implementing AMTs in manufacturing industries. Understanding complexity of operations performed is not laid-back phenomenon, it demands for vigorous efforts and dedication from each and every stakeholder to make it successful. AMTs is no more a buzzword in the present context of manufacturing era; its vitality is getting wider day by day. The paybacks of implementation of AMTs catching curiosity of researchers and industrialists to work in this domain. However, there are many issues while implementing Industry 4.0 like retrofitting of existing equipment or designing manufacturing system in compliance with AMTs, big data analytics to convert the data into useful information, cyber-security to ensure privacy of data etc.

Organizations must recognize their strength, weaknesses, opportunities, and threats towards AMTs implementation. Industry 4.0 have positive impact on manufacturing performance. In today's digital era, advanced technologies have touched every industrial sector. Extensive competitive pressure and dynamic customer demands urge industries to reorient their strategies to be in the marketplace. It has led to the emergence of AMTs and Industry 4.0 in the global landscape. Digitalization of manufacturing processes helps reduce wastages and emissions and optimize resource utilization and energy-saving. All these attributes contribute heavily to achieving sustainability. AMTs selection over traditional manufacturing was assessed using the AHP approach based on various parameters, including flexibility, cost, inventory, lead time, innovativeness, and productivity. It is found that priority weights of all these attributes of AMTs are more significant than traditional manufacturing. The next chapter talks about conclusion and managerial implications.

Chapter-8: Conclusion and Implications

Business innovations and technological gradations are rapidly increasing in today's competitive era. Organizations across the globe are highly passionate about AMTs implementation. Also, many organizations are improving their business model to enhance customer satisfaction. The research findings provide various implications for industry managers, practitioners, and policymakers. Firstly, the results indicated that AMTs implementation has enormous benefits over traditional manufacturing systems. Various AMTs barriers highlighted and assessed provide insights into the relative intensity of explored barriers. Financial and economic barriers were found to be topmost in all the categories. Horizontal and vertical integration can help industries connect with all the stakeholders across the supply chain and share data and information in real-time.

8.1 The Emergence of Advanced Manufacturing Technologies and Industry 4.0 in the Digital Era

Exponential growth and technological advancements have achieved Industry 4.0 goals and objectives. Most organizations in developing economies like India are still in the initial stage of Industry 4.0 implementation. So, organizations are moving towards digital transformations. Some researchers (Kadir and Broberg, 2020) defined the present manufacturing state as Industry 3.5, as organizations are halfway towards AMs implementation. Besides this, the Industry 5.0 concept is also introduced, focusing on mass personalization and collaborative robots.

High computational manufacturing systems and enhanced storage volume pave the pathway toward innovative technology adoption. It uses cyber-physical systems to send data from inter-connected physical equipment over wireless transmission networks. These intelligent technologies are not restricted only to the manufacturing sector, even the results are seen in other aspects also, for instance, smart homes (Mansouri et al., 2022), intelligent materials (Sagdic et al., 2022), innovative supply chain management (Wang et al., 2022), innovative society (Verma, 2022). AMTs implementation helps industries to have a competitive edge over other players in the market. The presented research discussed the key attributes, barriers, and critical success factors for AMTs implementation. AMTs implementation results in optimum utilization of resources, high accuracy of products with close dimensional tolerances, and increased safety of employees.

8.2 Implication for industries

The results help the managers to identify the root cause for failure in the context of AMTs implementation and develop suitable mitigation strategies to handle the issues. Practical and strategic dealing with identified barriers will result in decreased operational costs and improved manufacturing performance and quality.

AMTs implementation helps maximize manufacturing industries' social, economic, and environmental benefits. AMTs helps to improve each section's performance, including production, design, maintenance, procurement, finance, human resources, inventory, and stores. Even in the present scenario, all these sections are integrated with analytics to make real-time decisions. For instance, intelligent supply chain management helps organizations reduce supply-demand variability and increase supply chain performance.

Similarly, in maintenance, predictive analytics helps to tell the operator about scheduled maintenance schedules via text alerts so that necessary actions can be taken in advance to avoid last-minute chaos. However, AMTs implementation is subjected to various challenges. Strategic planning and coordination, top management support, employee empowerment, mutual trust and collaboration, and a continuous improvement system are crucial factors in

AMTs implementation. Strategic planning plays a significant role in organizational growth. It helps in clearly defining the objectives and goals of various departments, setting up equipment, workforce planning, production scheduling, and sequencing, among others. In traditional manufacturing systems, many times, due to the diversity of manufacturing, production managers need to be aware of the actual data of real-time production, which hinders investigating root cause analysis of the issues and effective decision making. Also, top management has made significant contributions to AMTs implementation. These are the officials who look after each aspect of business processes. The foremost objective of top management officials is to maximize operational efficiency and business performance. Top management must provide adequate resources to carry out organizational activities at the right time. It also ensures the hiring of skilled workforce as per the requirements and proper communication and assignment of job responsibilities.

Mutual trust and collaboration help in effective teamwork and coordination. The joint efforts of team members help to bring the ideas of different team members, which eventually helps in more innovative solutions to the identified problems. Collaborative strategies lead to reduce costs, enhanced sales and turnover, and explored new business opportunities. Therefore, collaboration helps in business growth, enhanced knowledge, and trust. Also, it is a win-win situation as all the associated parties benefit from it. Therefore, automotive manufacturers can collaborate with other players in the market to upgrade technologies.

SAP-LAP approach was used to analyze the AMTs challenges in the case organizations. This approach includes the situation, actors, process, learning, performance, and outcomes.

8.3 Implication for researchers

Advanced manufacturing technologies can have a significant impact on researchers in a number of ways.

- For researchers, advanced manufacturing technologies can provide new avenues for exploration and discovery.
- These technologies can enable the development of new materials, products, and processes, which can lead to innovative solutions to challenges faced by various industries.
- Additionally, the study of advanced manufacturing technologies can help researchers to better understand the underlying science and engineering principles that enable these technologies to function.
- Overall, the adoption of advanced manufacturing technologies can have far-reaching benefits for researchers, and as such, they are an important area of focus for both groups.

8.4 Research Limitations

- The present research was conducted in an emerging economy like India. The results may differ if the same research is carried out in distinct geographical locations across the globe.
- Since only a limited number of case studies were carried out in the automotive sector, the rigor may be absent to support the results in other industrial sectors.
- Due to time constraint, the presented study has not examined the skills required for successful AMT adoption, future studies can be done in this context

8.5 Scope For Future work

- For validation of findings empirical studies can be carried out in context to different manufacturing sector of India.
- Various research approaches like the Graph Theoretic Approach (GTA), Fuzzy-Technique of Order of Preference by Similarity to Ideal Solution (TOPSIS), and Analytic Hierarchy Process (AHP) was used to investigate the results.
- The results can be validated by interval-valued-based fuzzy MCDM approaches like Analytic Network Process (ANP) and Weighted Aggregated Sum Product Assessment (WASPAS).
- Furthermore, connection with AMT and sustainability dimensions can be explored and investigated.

8.6 Relevance for Industries and Researchers

Advanced manufacturing technologies can have a significant impact on industries and researchers in a number of ways. For industries, the adoption of advanced manufacturing technologies can lead to increased productivity, improved product quality, and reduced costs. These benefits can give companies a competitive advantage in their markets and allow them to produce goods more efficiently and effectively. For researchers, advanced manufacturing technologies can provide new avenues for exploration and discovery. These technologies can enable the development of new materials, products, and processes, which can lead to innovative solutions to challenges faced by various industries. Additionally, the study of advanced manufacturing technologies can help researchers to better understand the underlying science and engineering principles that enable these technologies to function. Overall, the adoption of advanced manufacturing technologies can have far-reaching benefits for both industries and researchers, and as such, they are an important area of focus for both groups.

References

1. Abd Rahman, A., & Bennett, D. (2009), “Advanced manufacturing technology adoption in developing countries: the role of buyer-supplier relationships” *Journal of Manufacturing Technology Management*, Vol.10, No.8, pp. 1099-1118.
2. Abd Rahmana, A. (2008), “Buyer-supplier relationships in advanced manufacturing technology acquisition and implementation in Malaysia”, *International Journal of Economics and Management*, Vol. 2, No.1, pp. 95-126.
3. Abdul-Hamid, A. Q., Ali, M. H., Tseng, M. L., Lan, S., & Kumar, M. (2020), “Impeding challenges on industry 4.0 in circular economy: Palm oil industry in Malaysia”, *Computers & Operations Research*, Vol. 123, Article No. 105052.
4. ACMA. (2011), “Indian automotive aftermarket study book”, *White Paper on Legislative Improvements to Combat Counterfeiting, press conference*, New Delhi, February.
5. Acemoglu, D., & Restrepo, P. (2020), “Robots and jobs: Evidence from US labor markets”, *Journal of Political Economy,* Vol. 128, No.6, pp. 2188-2244.
6. Adu-Amankwa, K., Attia, A. K., Janardhanan, M. N., & Patel, I. (2019), “A predictive maintenance cost model for CNC SMEs in the era of industry 4.0”, *The International Journal of Advanced Manufacturing Technology*, Vol. 104, No.9, pp. 3567-3587.
7. Agrawal, S., Singh, R.K., Murtaza, Q. (2016), “Outsourcing decisions in reverse logistics: Sustainable balanced scorecard and graph theoretic approach”, *Resources, Conservation and Recycling,* Vol.108, pp.41-53.
8. Agrawal, S., Singh, R.K., Murtaza, Q., (2016), “Disposition decisions in reverse logistics: Graph theory and matrix approach”, *Journal of Cleaner Production,* Vol.137, pp.93-104.
9. Akkari, A., Novaes, R.F.N. and Rocha, M.F.M. (2019), “Cognitive Ergonomics and the Industry 4.0: Emerging trends and challenges in Technology”, Proceedings of the 3rd Brazilian Technology Symposium, pp. 275-80.
10. Ahuja, I. P. S., and Khamba, J.S. (2008),“Strategies and Success Factors for Overcoming Challenges in TPM Implementation in Indian Manufacturing Industry”, *Journal of Quality in Maintenance Engineering,* Vol. 14, No.2, pp. 123–147.
11. Al-Qirim, N. (2007), “The adoption of ecommerce communications and application technologies in small businesses in New Zealand”, *Electronic Commerce Research and Applications*, Vol.6, No.4, pp.462-73.

12. Alkaraan, F., Albitar, K., Hussainey, K., & Venkatesh, V. (2022), “Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG)”, *Technological Forecasting and Social Change*, Vol. *175,* Article No. 121423.
13. Altuntas, S., Cinar, O., & Kaynak, S. (2018), “Relationships among advanced manufacturing technology, innovation, export, and firm performance: Empirical evidence from Turkish manufacturing companies”, *Kybernetes*, Vol.47, No.9, pp. 1836-56.
14. Anand, G. and Kodali, R. (2010), “A mathematical model for the evaluation of roles and responsibilities of human resources in a lean manufacturing environment”, *International Journal of Human Resources Development and Management*, Vol.10, No.1, pp.63-100.
15. Anand, G., and Bahinipati. B.K. (2012), “Measuring Horizontal Collaboration Intensity in Supply Chain: A Graph-theoretic Approach”,*Production Planning and Control*, Vol. 23, No.10–11, pp.801–816.
16. Anbanandam, R., Banwet, D.K. and Shankar, R. (2011), “Evaluation of supply chain collaboration: a case of apparel retail industry in India”, *International Journal of Productivity and Performance Management*, Vol. 60, No.2, pp.82-98.
17. Ariansyah, D., Erkoyuncu, J. A., Eimontaite, I., Johnson, T., Oostveen, A. M., Fletcher, S., & Sharples, S. (2022), “A head mounted augmented reality design practice for maintenance assembly: Toward meeting perceptual and cognitive needs of AR users”, *Applied Ergonomics*, Vol. *98,* Article No. 103597.
18. Arromba, I. F., Martin, P. S., Ordoñez, R. C., Anholon, R., Rampasso, I. S., Santa-Eulalia, L. A., ... & Quelhas, O. L. G. (2021), “Industry 4.0 in the product development process: Benefits, difficulties and its impact in marketing strategies and operations”, *Journal of Business & Industrial Marketing*, Vol.36, No.3, pp. 522-34.
19. Asadzadeh, S. (2022), “Statistical process control based on gamma-frailty models for heterogeneous reliability observations”, *Journal of Statistical Computation and Simulation*, Vol. 92, No.2, pp. 337-351.
20. Attri, R., Grover, S., Dev, N.and Kumar, D.(2012a), “Analysis of Barriers of Total Productive Maintenance (TPM)”,*International Journal System Assurance Engineering and Management*, Vol. 4, No.4, pp.365–377.
21. Awasthi, A., Govindan, K., & Gold, S. (2018), “Multi-tier sustainable global supplier selection using a fuzzy AHP-VIKOR based approach”, *International Journal of Production Economics*, Vol. 195, pp. 106-117.

22. Ayvaz, S., & Alpay, K. (2021), “Predictive maintenance system for production lines in manufacturing: A machine learning approach using IoT data in real-time”, *Expert Systems with Applications*, Vol. 173, Article No. 114598.
23. Baas, L. (2007), “To make zero emissions technologies and strategies become a reality, the lessons learned of cleaner production dissemination have to be known”, *Journal of Cleaner Production*, Vol.15, pp.1205-1216.
24. Baeno, F., Guarin, A., Mora, J., Sauza, J. and Retat, S. (2017), “Learning factory: The path to Industry 4.0”, *Procedia Manufacturing*, Vol. 9, pp. 73-80.
25. Baglee, D. and Knowles, M. (2010), “Maintenance Strategy Development Within SMEs: The Development of an Integrated Approach”, *Control and Cybernetics*, Vol. 39, No.1, pp.275–303.
26. Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2020), “Industry 4.0 technologies assessment: A sustainability perspective”,*International journal of production economics*, Vol. 229, Article No. 107776.
27. Bainbridge, L. (1983), “Ironies of automation”, In *Analysis, design and evaluation of man–machine systems* (pp. 129-135). Pergamon.
28. Balakrishnan, A. S., & Ramanathan, U. (2021), “The role of digital technologies in supply chain resilience for emerging markets’ automotive sector”, *Supply Chain Management: An International Journal*, Vol.26, No.6, pp. 654-71.
29. Ballestar, M. T., Díaz-Chao, Á., Sainz, J., & Torrent-Sellens, J. (2021), “Impact of robotics on manufacturing: A longitudinal machine learning perspective”, *Technological Forecasting and Social Change*, Vol. 162, Article No.120348.
30. Barua, B., & Islam, M. O. (2008), “Key success factors for implementation of advanced manufacturing technologies (AMTSs)-case study conducted on selected pharmaceutical companies in Bangladesh”, *BUS-ECON*, Vol. 8, No.2, pp. 53-67.
31. Barve, A., Kanda, A., & Shankar, R. (2009), “The role of human factors in agile supply chains”, *European Journal of Industrial Engineering*, Vol. 3, No.1, pp. 2-20.
32. Bayazit, O. (2005), “Use of AHP in decision-making for flexible manufacturing systems”, *Journal of Manufacturing Technology Management*, Vol.16, No. 7, pp.808–819.
33. Beaumont, N.B. and Schroder, R.M. (1997), “Technology, manufacturing performance and business performance amongst Australian manufacturers”, *Technovation*, Vol.17, No. 6, pp. 297-307.

34. Bergenwall, A. L., Chen, C., & White, R. E. (2012), “TPS's process design in American automotive plants and its effects on the triple bottom line and sustainability”, *International Journal of Production Economics*, Vol. 140, No.1, pp. 374-384.
35. Bhandari, D., Singh, R. K., & Garg, S. K. (2018), “Justification of advanced manufacturing technologies for small and medium enterprises from auto component sector: AHP approach”, *International Journal of Productivity and Quality Management*, Vol. 23, No.4, pp. 473-491.
36. Bhaskar, V.V. (2013), “Indian Auto Component Industry: A Decade of Growth and Way Forward”, *Research Journal of Management Sciences*, Vol. 23, No. 3, pp. 19-27.
37. Bhatt, P. M., Malhan, R. K., Shembekar, A. V., Yoon, Y. J., & Gupta, S. K. (2020), “Expanding capabilities of additive manufacturing through use of robotics technologies: A survey”, *Additive manufacturing*, Vol. 31, Article No.100933.
38. Bhise, D. V., & Sunnapwar, V. K. (2019), “Developing framework for the implementation of advanced manufacturing technologies in small and medium-sized enterprises”, *International Journal of Applied Management and Technology*, Vol. 18, No.1, pp.1- 10.
39. Borregan-Alvarado, J., Alvarez-Meaza, I., Cilleruelo-Carrasco, E., & Garechana-Anacabe, G. (2020), “A bibliometric analysis in industry 4.0 and advanced manufacturing: What about the sustainable supply chain?”, *Sustainability*, Vol. 12, No.19, Article No. 7840.
40. Boyer, K. K., & Pagell, M. (2000), “Measurement issues in empirical research: improving measures of operations strategy and advanced manufacturing technology”, *Journal of Operations Management*, Vol. 18, No.3, pp. 361-374.
41. Boyer, K. K., Ward, P. T. and Leong, G. K., (1996), “Approaches to the factory of the future. an empirical taxonomy”, *Journal of Operations Management*, Vol.14, pp. 297–313.
42. Boyer, K. K., Leong, G. K., Ward, P. T., & Krajewski, L. J. (1997), “Unlocking the potential of advanced manufacturing technologies”, *Journal of operations management*, Vol. 15, No.4, pp. 331-347.
43. Boyle, T.A. (2006), “Towards best management practices for implementing manufacturing flexibility”, *Journal of Manufacturing Technology Management*, Vol. 17 No. 1, pp. 6-21.
44. Bressanelli, G., Adrodegari, F., Perona, M., & Saccani, N. (2018), “Exploring how usage-focused business models enable circular economy through digital technologies”, *Sustainability*, Vol. 10, No.3.
45. Büchi, G., Cugno, M., & Castagnoli, R. (2020), “Smart factory performance and Industry 4.0”, *Technological Forecasting and Social Change*, Vol. 150, 119790, https://doi.org/10.1016/j.techfore.2019.119790.

46. Bulbul, H., Ömürbek, N., Paksoy, T., & Bektaş, T. (2013), "An empirical investigation of advanced manufacturing technology investment patterns: Evidence from a developing country", *Journal of Engineering and Technology Management*, Vol. 30, No.2, pp. 136-156
47. Burova, A., Mäkelä, J., Heinonen, H., Palma, P. B., Hakulinen, J., Opas, V., ... & Turunen, M. (2022), "Asynchronous industrial collaboration: How virtual reality and virtual tools aid the process of maintenance method development and documentation creation", *Computers in Industry*, Vol. 140, Article No. 103663
48. Broo, D. G. (2022), "Transdisciplinarity and three mindsets for sustainability in the age of cyber-physical systems", *Journal of Industrial Information Integration*, Vol. *27*, Article No. 100290.
49. Brown, S. (2000), "Manufacturing the Future: Strategic Resonance for Enlighted Manufacturing, Prentice-Hall", Harlow.
50. Cagliano, R., & Spina, G. (2000), "Advanced manufacturing technologies and strategically flexible production", *Journal of operations Management*, Vol. 18, No.2, pp.169-190.
51. Calabrese, A., Levialdi Ghiron, N., & Tiburzi, L. (2021), "Evolutions' and 'revolutions' in manufacturers' implementation of industry 4.0: a literature review, a multiple case study, and a conceptual framework", *Production Planning & Control*, Vol. 32, No.3, pp. 213-227.
52. Chand, P., Thakkar, J. J., & Ghosh, K. K. (2018), "Analysis of supply chain complexity drivers for Indian mining equipment manufacturing companies combining SAP-LAP and AHP", Resources Policy, Vol. 59, pp. 389-410.
53. Charaf, K., Rahmounib, A. F. A., & Sabar, M. (2022), "The association between Activity-Based Costing and performance: Empirical evidence from Moroccan companies", *Accounting and Management Information Systems*, Vol. *21*, No.1, pp. 25-45
54. Chavan, M., Chandiramani, J., & Nayak, S. (2019), "Assessing the state of physical infrastructure in progressive urbanization strategy: SAP-LAP analysis", Habitat International, Vol. 89, Article No.102002.
55. Chauhan, C., Singh, A., & Luthra, S. (2021), "Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy", *Journal of Cleaner Production*, Vol. *285*.
56. Chang, T. H., & Wang, T. C. (2009), "Measuring the success possibility of implementing advanced manufacturing technology by utilizing the consistent fuzzy preference relations", *Expert Systems with Applications*, Vol. 3*6*, No.3, pp. 4313-4320
57. Chen, I. J., & Small, M. H. (1994), "Implementing advanced manufacturing technology: an integrated planning model", *Omega*, Vol. *22*, No.1, pp. 91-103

58. Chen, I.J. and Small, M.H. (1996), "Planning for advanced manufacturing technology: research framework", *International Journal of Operations & Production Management,* Vol. 16, No. 5, pp. 4-24.

59. Chen, Y., Han, Z., Cao, K., Zheng, X., & Xu, X. (2020), "Manufacturing upgrading in industry 4.0 era", *Systems Research and Behavioral Science,* Vol. 37, No.4, pp. 766-771

60. Chen, W., Gong, Y., & de Koster, R. B. (2022), "Performance estimation of a passing-crane automated storage and retrieval system", *International Journal of Production Research,* Vol. 60, No.4, pp. 1210-1230

61. Cheng, Y., Matthiesen, R., Farooq, S., Johansen, J., Hu, H., & Ma, L. (2018), "The evolution of investment patterns on advanced manufacturing technology (AMTs) in manufacturing operations: A longitudinal analysis", *International Journal of Production Economics,* Vol. 203, pp. 239-253.

62. Chien, C. F., & Hong, T. Y. (2022), "An integrated framework of Industry 3.5 and an empirical study of simulation-based automated material handling system for semiconductor manufacturing", *International Journal of Logistics Research and Applications*, pp. 1-17

63. Chin, K.S., Chiu, S. and Tummala, V.M.R. (1999), ''An evaluation of success factors using the AHP to implement ISO 14001-based ESM'', *International Journal of Quality & Reliability Management,* Vol. 16 No. 4, pp. 341-61

64. Choudhury, A. K., Shankar, R., & Tiwari, M. K. (2006), "Consensus-based intelligent group decision-making model for the selection of advanced technology", *Decision Support Systems*, Vol. *42,* No.3, pp. 1776-1799

65. Chougale, P.R. and Pethkar, S.M. (2016), "Advance Manufacturing Technology", *International conference on Recent Innovations in Engineering and management,* 23rd March 2016, ISBN: 978-81932074-5-1.

66. CII-PwC (2022), "Manufacturing technology in the automotive sector: Prospects of eastern India",https://www.pwc.in/assets/pdfs/publications/2018/manufacturing-technology-in-the-automotive-sector-prospects-of-eastern-india.pdf, Accessed on August 09, 2022.

67. Costa, S.E., Platts, K.W. and Fleury, A. (2006), "Strategic selection of advanced manufacturing technologies (AMTS), based on the manufacturing vision*", International Journal of Computer Applications in Technology,* Vol. 27, No. 1, pp. 12-23

68. Costa, G. D. M., Petry, M. R., & Moreira, A. P. (2022), "Augmented Reality for Human–Robot Collaboration and Cooperation in Industrial Applications: A Systematic Literature Review", *Sensors,* Vol. *22,* No.7, Article No. 272

69. Cook, J. S., & Cook, L. L. (1994), "Achieving competitive advantages of advanced manufacturing technology", *Benchmarking for Quality Management & Technology*, Vol.1, No.2, pp. 42-63.
70. Culot, G., Nassimbeni, G., Orzes, G. and Sartor, M. (2020), "Behind the definition of Industry 4.0: analysis and open questions", *International Journal of Production Economics*.
71. D'Aveni, R., 2015. The 3-D printing revolution. In: Harvard Business Review, Vol. 93. Retrieved from. https://hbr.org/2015/05/the-3-d-printing-revolution, accessed on July 10, 2023.
72. Da Costa, S. G., & de Lima, E. P. (2009), "Advanced manufacturing technology adoption: an integrated approach", *Journal of Manufacturing Technology Management*, Vol.20, No.1, pp. 74-96
73. Da Rosa Cardoso, R., de Lima, E. P., & da Costa, S. E. G. (2012), "Identifying organizational requirements for the implementation of Advanced Manufacturing Technologies (AMTS)", *Journal of Manufacturing Systems*, Vol. 31, No.3, pp. 367-378.
74. Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018), "The expected contribution of Industry 4.0 technologies for industrial performance", *International Journal of production economics*, Vol. 204, pp. 383-394
75. Dangayach, G.S. and Deshmukh, S.G. (2001), "Practice of manufacturing strategy: evidences from select Indian automobile companies", *International Journal of Production Research*, Vol. 39, No. 11, pp. 2353-93.
76. Dangyanch, G.S. and Deshmukh, S.G. (2003), "Evidence of manufacturing strategies in Indian industry", *International Journal of Production Economics*, Vol.83, No.3, pp.279-298.
77. Dangayach, G.S. and Deshmukh, S.G. (2005), "Advanced manufacturing technology implementation", *Journal of Manufacturing Technology Management*, Vol. 16, No.5, pp. 483 – 49
78. Dawal, S.Z.M., Tahiri, F., Jen, Y.H., Case, K., Tho, N.H., Zuhidi, A., Mousavi, M., Amindoust, A. and Sakundarini, A. (2015), "Empirical evidence of AMTS practices and sustainable environmental initiatives in malaysian automotive SMEs", *International journal of precision Engineering and Manufacturing*, Vol.16, No.6, pp.1195-1203.
79. Dean Jr, J. W., Yoon, S. J., & Susman, G. I. (2008), "Advanced manufacturing technology and organization structure: empowerment or subordination?", *Organization Science*, Vol. *3*, No.2, pp. 203-229
80. DeCanio, S. And Watkins, W. (1998), "Investment in energy efficiency: do the characteristics of the firms matter"? *The Review of Economics and Statistics*, Vol. 80, No.1,pp.95-107.

81. De Groot, H., Verhoef, E., and Nijkamp P. (2001), "Energy saving by firms: decisionmaking, barriers and policies", *Energy Economics*, Vol.23, No.6, pp.717-740.
82. De Ryck, M., Versteyhe, M., & Debrouwere, F. (2020), "Automated guided vehicle systems, state-of-the-art control algorithms and techniques", *Journal of Manufacturing Systems*, Vol. 54, pp. 152-173
83. De Sousa Jabbour, A. B. L., Jabbour, C. J. C., Foropon, C., & Godinho Filho, M. (2018), "When titans meet–Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors", *Technological Forecasting and Social Change*, Vol. 132, pp. 18-25.
84. Delera, M., Pietrobelli, C., Calza, E., & Lavopa, A. (2022), "Does value chain participation facilitate the adoption of Industry 4.0 technologies in developing countries?", *World Development*, Vol. *152*, Article No. 105788.
85. Deloitte (2020), "Industry 4.0 in automotive. Digitizing the end-to-end automotive supply chain",https://www2.deloitte.com/content/dam/insights/us/articles/automotive_news_industry-4-0-in-automotive/DI_Automotive-News-Supplement.pdf. Accessed on August 09, 2022
86. Demirel, P. And Parris, S. (2015), "Access to finance for innovators in the UK's environmental sector" *Technology Analysis and Strategic Management*, Vol.27 No.7, pp.1–27.
87. Diaz-Reza, J.R, Mendoza-Fong, J.R., Blanco-Fernandez, J., Marmolejo-Saucedo, J.A. and Garcia-Alcaraz, J.L. (2019), "The role of Advanced Manufacturing Technologies in production process performance: A Casual Model", *Applied Sciences*, Vol. 9, pp. 1-21.
88. Dixit, A., Jakhar, S. K., & Kumar, P. (2022), "Does lean and sustainable manufacturing lead to Industry 4.0 adoption: The mediating role of ambidextrous innovation capabilities", *Technological Forecasting and Social Change*, Vol. 175, Article No. 121328.
89. Dubey, R., Gunasekaran, A., Papadopoulos, T., Childe, S. J., Shibin, K. T. and Wamba, S. F. (2017),"Sustainable supply chain management: framework and further research directions", *Journal of Cleaner Production*, Vol.142, pp.1119-1130.
90. Dutta, G., Kumar, R., Sindhwani, R., & Singh, R. K. (2021),"Digitalization priorities of quality control processes for SMEs: A conceptual study in perspective of Industry 4.0 adoption", *Journal of Intelligent Manufacturing*, Vol. 32, No.6, pp.1679-1698
91. Dwivedi, G., Srivastava, S. K., & Srivastava, R. K. (2017), "Analysis of barriers to implement additive manufacturing technology in the Indian automotive sector", *International Journal of Physical Distribution & Logistics Management*, Vol. 47, No.10, pp. 972-91

92. Efstathiades, A., Tassou, S., & Antoniou, A. (2002), “Strategic planning, transfer and implementation of Advanced Manufacturing Technologies (AMTs): Development of an integrated process plan”, *Technovation,* Vol. 22, No.4, pp. 201-212.
93. Eisenack, K. and Petschel-Held, G. (2002), “Graph theoretical analysis of qualitative modelsin sustainability science”,*In Working papers of 16th workshop on qualitative reasoning*,pp.53-60.
94. Eisenhardt, K. M. (1989), “Building theories from case study research”, *Academy of Management Review,* Vol. 14, No.4, pp. 532-550.
95. Erol, S., Jager, A., Hold, P., Ott, K., Sihn, W. (2016), “Tangible Industry 4.0: a scenario-based approach to learning for the future of production”, *6th CIRP conference on learning factories, Procedia CIRP*, Vol. 54, pp. 13-18
96. Errandonea, I., Beltrán, S., & Arrizabalaga, S. (2020), “Digital Twin for maintenance: A literature review”, *Computers in Industry,* Vol. 123, Article No. 103316
97. Faisal, M.N., Banwet, D.K. and Shankar, R.(2006), “Mapping supply chains on risk and customer sensitivity dimensions”, *Industrial Management and Data Systems*, Vol. 106, No.6, pp.878-895
98. Fareri, S., Fantoni, G., Chiarello, F., Coli, E. and Binda, A. (2020), “Estimating industry 4.0 impact on job profiles and skills using text mining”, *Computers in Industry*.
99. Ford, S., & Despeisse, M. (2016), “Additive manufacturing and sustainability: an exploratory study of the advantages and challenges”,*Journal of cleaner Production,* Vol. 137, pp.1573-1587
100. Frank, A.G., Cortimigila, M.N., Ribeiro, J.L.D. and Oliveira, L.S. (2016), “The effect of innovation activities on innovation outputs in the Brazilian industry: Market-orientation vs. technology-acquisition strategies”, *Research Policy,* Vol.45, pp. 577-92.
101. Frank, A. G., Mendes, G. H., Ayala, N. F., & Ghezzi, A. (2019), “Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective”, *Technological Forecasting and Social Change,* Vol. 141, pp. 341-351.
102. Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A. and Anderson, D. (2005), “UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures”,*Energy Policy,* Vol.33, No.16,pp.2123-2137.
103. Gajek, A., Fabiano, B., Laurent, A., & Jensen, N. (2022), “Process safety education of future employee 4.0 in Industry 4.0”, *Journal of Loss Prevention in the Process Industries,* Vol. 75, Article No. 104691.

104.Garg, A. and Deshmukh, S.G. (2010), "Engineering support issues for flexibility in maintenance: An SAP-LAP framework", *Asia Pacific Journal of Marketing and Logistics*, Vol. 22 No. 2, pp. 247-270. https://doi.org/10.1108/13555851011026980

105.Gasova, M., Stefanik, A. and Gaso, M. (2017), “Advanced Industrial tools of ergonomics based on Industry 4.0 concept”, *Procedia Engineering,* Vol.192, pp. 219-24.

106.Ghani, K. A., Jayabalan, V., & Sugumar, M. (2002), “Impact of advanced manufacturing technology on organizational structure”, *The Journal of High Technology Management Research,* Vol. *13,* No.2, pp. 157-175.

107.Ghobakhloo, M. (2020), “Industry 4.0, digitization, and opportunities for sustainability”, *Journal of cleaner production,* Vol. *252,* Article No. 119869.

108.Ghobakhloo, M., &Azar, A. (2017), “Business excellence via advanced manufacturing technology and lean-agile manufacturing”, *Journal of Manufacturing Technology Management,* Vol. 29, No.1, pp. 2-24

109.Gloet, M., & Samson, D. (2022), “Knowledge and innovation management to support supply chain innovation and sustainability practices”, *Information Systems Management,* Vol. *39,* No.1, pp. 3-18.

110.Goel, P., Kaushik, N., Sivathanu, B., Pillai, R., & Vikas, J. (2022), “Consumers’ adoption of artificial intelligence and robotics in hospitality and tourism sector: literature review and future research agenda”, *Tourism Review,* Vol.77, No.4, pp. 1081-96.

111.Goh, M. M., Tan, A. B., & Leong, M. H. (2016), “Bar Code–Based Management to Enhance Efficiency of a Sterile Supply Unit in Singapore”, *AORN journal,* Vol. *103,* No.4, pp. 407-413.

112.Gouvea Da Costa, S. E., Platts, K. W., & Fleury, A. (2006), “Strategic selection of advanced manufacturing technologies (AMTS), based on the manufacturing vision”, *International Journal of Computer Applications in Technology,* Vol. *27,* No.1, pp.12-23

113.Govindarajulu, N. and Daily, B.F.(2004), “Motivating employees for environmental improvement”, *Industrial Management & Data Systems,*Vol.104, No.4, pp.364–72.

114.Griffiths, A. and Petrick, J.A., (2001), “Corporate architectures for sustainability” *International Journal of Operations and Production Management,* Vol. 21, No. 12, pp. 1573-1585.

115.Grover, S., Agrawal, V.P and Khan, I.A. (2006), “Role of Human Factor in TQM: A Graph Theoretic Approach”, Benchmarking: *An International Journal,* Vol. 13, No.4, pp. 447–468.

116.Guillaume, R., Thierry, C., & Zieliński, P. (2017), “Robust material requirement planning with cumulative demand under uncertainty”, *International Journal of Production Research,* Vol. *55,* No.22, pp. 6824-6845

117.Gunasekaran, A., Yusuf, Y. Y., Adeleye, E. O., Papadopoulos, T., Kovvuri, D., & Geyi, D. A. G. (2019), "Agile manufacturing: an evolutionary review of practices", *International Journal of Production Research*, Vol. 57, No.15-16, pp. 5154-5174

118.Gunasekaran, A. and Spalanzani, A. (2012), "Sustainability of manufacturing and services: Investigations for research and applications",*International Journal of Production Economics,* Vol.140, No.1, pp.35-47.

119.Gunningham, N. and Sinclair, D. (1997), "Barriers and Motivators to the Adoption of Cleaner Production Practices, produced for Environment Australia", *Australian Centre for Environmental Law,* Australian National University, Canberra.

120.Gupta, A., & Singh, R. K. (2020), "Managing operations by a logistics company for sustainable service quality: Indian perspective", *Management of Environmental Quality: An International Journal*, Vol. 31, No.5, pp. 1309-1327.

121.Gupta, A., Singh, R. K., & Mangla, S. K. (2021), "Evaluation of logistics providers for sustainable service quality: Analytics based decision making framework", *Annals of Operations Research*, 1-48

122.Hafez, S. (1994), "Financing Cleaner Production in Developing Countries", *UNEP Industry and Environment*, Vol.17, No.55, pp.75-77

123.Hamed, M.M.E. and Mahgary, E.I. (2004), "Outline of a national strategy for cleaner production: The case of Egypt", *Journal of Clean Production*, Vol.12, No.4, pp.327-336

124.Harris, J., Anderson, J. and Shafron, W. (2000), "Investment in energy efficiency: a survey of Australian firms", *Energy Policy*, Vol. 28, No.12, pp.867-876.

125.Hartmann, J. and Moeller, S. (2014), "Chain liability in multitier supply chains? Responsibility attributionsfor unsustainable supplier behavior",*Journal of Operations Management,* Vol.32, No.5,pp.281–294.

126.Hilson,G. (2000), "Barriers to implementing AMTs and cleaner production (CP) practices in the mining industry: A case study of the Americas", *Journal of Minerals Engineering*, Vol.13, No.7, pp.699-717.

127.Hitt, M.A., Ireland, R.D. and Hoskisson, R.E. (2001), "Strategic Management-competitiveness and Globalisation-concepts and Cases", *Thompson Learning, Mason*, OH.

128.Horvath, D. and Szabo, R.Z. (2019), "Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?", Technology Forecasting and Social Change, Vol. 146, pp. 119-132.

129.Hoyer, C., Gunawan, I., & Reaiche, C. H. (2020), "The implementation of industry 4.0–a systematic literature review of the key factors", *Systems Research and Behavioral Science*, Vol.37, No.4, pp. 557-578.

130.Hu, R., Shahzad, F., Abbas, A., & Liu, X. (2022), "Decoupling the influence of eco-sustainability motivations in the adoption of the green industrial IoT and the impact of advanced manufacturing technologies", *Journal of Cleaner Production*, Vol. 339, Article No. 130708.

131.Huang, R., Riddle, M., Graziano, D., Warren, J., Das, S., Nimbalkar, S., ... & Masanet, E. (2016), "Energy and emissions saving potential of additive manufacturing: the case of lightweight aircraft components", *Journal of cleaner production,* Vol. 135, Article No. 1559-1570.

132.Huerta-Torruco, V. A., Hernández-Uribe, Ó., Cárdenas-Robledo, L. A., & Rodríguez-Olivares, N. A. (2022), "Effectiveness of virtual reality in discrete event simulation models for manufacturing systems", *Computers & Industrial Engineering*, Vol. 168.

133.Hwang, G., Lee, J., Park, J. and Chang, T-W. (2017), "Developing performance measurement system for internet of things and smart factory environment", International Journal of Production Research, Vol.55, No.9, pp. 2590-260

134.Hynek. J and Janecek V. (2013), "Issues affecting Advanced Manufacturing Technology projects" in *Advances in Sustainable and Competitive Manufacturing* Systems, *A. Azevedo, Ed. Switzerland: Springer International Publishing*, Vol. I, pp. 775-784.

135.IBEF (2022), https://www.ibef.org/download/1658816508_Automobile-PPT-June-2022.pdf

136.Isa, C.R. and Foong, S.Y. (2005), "Adoption of advanced manufacturing technology (AMTS) and management accounting practices: the case of manufacturing firms in Malaysia", *World Review of Science, Technology and Sustainable Development*, Vol. 2, No. 1, pp. 35-48

137.Islam, M. A. (2022), "Industry 4.0: Skill set for employability", *Social Sciences & Humanities Open*, Vol. *6,* No.1, Article No. 100280

138.Jacobsson, S. and Karltorp, K. (2013), "Mechanisms blocking the dynamics of the European offshore wind energy innovation system – Challenges for policy intervention", Energy *Policy,* Vol.63, pp.1182–1195.

139.Jaffe, A. and Stavins, R. (1994), "The energy efficiency gap. What does it mean"? *Energy Policy,* Vol. 22, No.10, pp.804-810.

140.Jin, M., Tang, R., Ji, Y., Liu, F., Gao, L., & Huisingh, D. (2017), "Impact of advanced manufacturing on sustainability: An overview of the special volume on advanced manufacturing for sustainability and low fossil carbon emissions", *Journal of cleaner production,* Vol. 161, pp. 69-74.

141.Jiao, J., Zhou, F., Gabraeel, N.Z. and Duffy, V. (2020), "Towards augmenting cyber-physical-human collaborative cognition for human-automation interaction in complex manufacturing and operational environments", *International Journal of Production Research*.

142.Jonsson, P. (2000), "An empirical taxonomy of advanced manufacturing technology", *International Journal of Operations & Production Management*, Vol.20, No.12, pp. 1446-74.

143.Johnston, C. (2022), "Ethical design and use of robotic care of the elderly", *Journal of Bioethical Inquiry*, Vol. *19,* No.1, pp. 11-14.

144.Jones, M. A., Wyld, D. C., & Totten, J. W. (2022), "The adoption of RFID technology in the retail supply chain", *The Coastal Business Journal*, Vol.4, No.1, Article No.4..

145.Junior, J. A. G., Busso, C. M., Gobbo, S. C. O., & Carreão, H. (2022), "Making the links among environmental protection, process safety, and industry 4.0", *Process safety and environmental protection*, Vol. 117, pp. 372-382.

146.Jurkat,W.B. and Ryser, H.J. (1966), "Matrix factorization of determinants and permanents",*Journal of Algebra*, Vol.3, No.1, pp.1-27.

147.Kablan, M. (2003), "Energy conservation projects implementation at Jordan's industrial sector: a total quality management approach", *Energy,*Vol.28, No.15, pp.1533-1543.

148.Kadir, B. A., & Broberg, O. (2020), "Human well-being and system performance in the transition to industry 4.0", *International Journal of Industrial Ergonomics*, Vol. 76, 102936.

149.Kadir, B. A., Broberg, O., & da Conceicao, C. S. (2019), "Current research and future perspectives on human factors and ergonomics in Industry 4.0", *Computers & Industrial Engineering*, Vol. *137,* Article No. 106004.

150.Kagermann, W.W.H., Helbig, J., Wahlster, W. (2013), "Recommendations for implementing the strategic initiatives Industry 4.0", Final report of Industry 4.0 working group, pp. 1-84.

151.Kamble, S. S., Gunasekaran, A., & Sharma, R. (2018),"Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry", *Computers in Industry,* Vol. 101, pp. 107-119

152.Kaasinen, E., Schmalfuß, F., Özturk, C., Aromaa, S., Boubekeur, M., Heilala, J., ... & Walter, T. (2020), "Empowering and engaging industrial workers with Operator 4.0 solutions", *Computers & Industrial Engineering*, Vol. *139,* Article No. 105678

153.Kaur, A., Kanda, A. and Deshmukh, S.G. (2006), "A graph theoretic approach for supply chain coordination", *International Journal of Logistics and System Management*, Vol.2, No.4, pp.321-341

154. Kazancoglu, Y. and Ozkan-Ozen, Y. (2018), "Analyzing Workforce 4.0 in the Fourth Industrial Revolution and proposing a road map from operations management perspective with fuzzy DEMATEL", Journal of Enterprise Information Management, Vol. 31 No. 6, pp. 891-907
155. Kennedy, J. and Hyland, P. (2003), "A comparison of manufacturing technology adoption in SMEs and large companies", *A paper for the Small Enterprise Association of Australia and New Zealand 16th Annual Conference, Ballarat*, 28 Sept-1 Oct, 2003
156. Kerin, M., & Pham, D. T. (2019), "A review of emerging industry 4.0 technologies in remanufacturing", *Journal of cleaner production*, Vol. *237*, Article No. 117805
157. Khalili, N. R., Duecker, S., Ashton, W. and Chavez, F. (2014), "From cleaner production to sustainable development: the role of academia", *Journal of Cleaner Production*, Vol.96, No., No.1, pp.33-43
158. Khazanchi, S., Lewis, M. W. and Boyer, K. K. (2007), "Innovation-supportive culture: the impact of organizational values on process innovation", *Journal of Operations Management,* Vol.25, No. 4, pp.871-84
159. Kiran, C. P., Clement, S. and Agrawal, V.P. (2012), "Quality Modelling and Analysis of a Mechatronic System", *International Journal of Industrial and Systems Engineering*, Vol. 12, No.1, pp.1–28
160. Kroll, H., Copani, G., Van de Velde, E., Simons, M., Horvat, D., Jäger, A., ... & Naumanen, M. (2016), "An analysis of drivers, barriers and readiness factors of EU companies for adopting advanced manufacturing products and technologie", https://data.europa.eu/doi/10.2873/715340.
161. Koefoed,M. and Buckley,C. (2008), "Clean technology transfer: a case study from the South African metal finishingindustry", *Journal of Clean Production*, Vol.16, No.1, pp.S78-S84.
162. Kong, T., Feng, T., & Ye, C. (2016). Advanced manufacturing technologies and green innovation: The role of internal environmental collaboration. *Sustainability*, *8*(10), 1056.
163. Kumar, R., Singh, H., & Chandel, R. (2017), "Exploring the key success factors of advanced manufacturing technology implementation in Indian manufacturing industry", *Journal of Manufacturing Technology Management*, Vol. 29, No.1, pp. 25-40.
164. Lagace, D. and Bourgault, M. (2003), "Linking manufacturing improvement programs to the competitive priorities of Canadian SMEs", *Technovation*, Vol. 23, pp. 705-15
165. Laudante, E. (2017), "Industry 4.0, Innovations and Design", A new approach for ergonomic analysis in manufacturing system", *The Design Journal*, Vol. 20, pp. 2724-34

166.Leete, S., Xu, J. and Wheeler, D. (2013), “Investment barriers and incentives for marine renewable energy in the UK: An analysis of investor preferences”, *Energy Policy,* Vol.60, No.3, pp.866–875.

167.Lee, J., Cameron, I., & Hassall, M. (2019), “Improving process safety: What roles for Digitalization and Industry 4.0?”, *Process safety and environmental protection,* Vol. 132, pp. 325-339

168.Li, B., Zhang, H., Ye, P., & Wang, J. (2020), “Trajectory smoothing method using reinforcement learning for computer numerical control machine tools”, *Robotics and Computer-Integrated Manufacturing,* Vol. 61, Article No. 101847

169.Li, L., Lei, B., & Mao, C. (2022), “Digital twin in smart manufacturing”, *Journal of Industrial Information Integration,* Vol. 26, Article No. 100289

170.Liao, Y., F. Deschamps, Loures, E. D. F. R. and Ramos, L. F. P. (2017), “Past, Present and Future of Industry 4.0 – a Systematic Literature Review and Research Agenda Proposal.” *International Journal of Production Research,* Vol. 55, No.12, pp. 3609–3629.

171.Lin, K. Y. (2018), “User experience-based product design for smart production to empower industry 4.0 in the glass recycling circular economy”, *Computers & Industrial Engineering,* Vol. 125, pp. 729-738

172.Liu, S., Leat, M. and Smith, M.H. (2011), “State-of-the-art sustainability analysis methodologiesfor efficient decision support in green production operations”, *International Journal of Sustainable Engineering,* Vol. 4, No.3, pp.236-250

173.Liu, Y. (2014), “Barriers to the Adoption of Low Carbon Production: A Multiple-case Study of Chinese Industrial Firm”,*Energy Policy,* Vol.67, pp.412–421.

174.Liu, C., & Xu, X. (2017), “Cyber-physical machine tool–the era of machine tool 4.0”, *Procedia Cirp,* Vol. *63,* pp. 70-75

175.Liu, C., Zhu, H., Tang, D., Nie, Q., Zhou, T., Wang, L., & Song, Y. (2022), “Probing an intelligent predictive maintenance approach with deep learning and augmented reality for machine tools in IoT-enabled manufacturing”, *Robotics and Computer-Integrated Manufacturing,* Vol. *77,* Article No. 102357

176.Longo, F., Nicoletti, E., Padovano, A. (2017), “Smart operators in industry 4.0: A human-centered approach to enhance operator’s capabilities and competencies within the new smart factory context. Computers and Industrial Engineering, Vol. 113, pp. 144-159.

177.Longo, F., Nicoletti, L., Padovano, A., d'Atri, G., & Forte, M. (2019), “Blockchain-enabled supply chain: An experimental study”, *Computers & Industrial Engineering,* Vol. 136, pp. 57-69

178.Lopes, S., D. A., Delai, I., Soares de Castro, M. A. and Ometto, A. R. (2013), “Quality tools applied to Cleaner Production programs: a first approach toward a new methodology”, *Journal of Cleaner Production*, Vol.47, pp.174–187.

179.Lorenz, M., Rüssmann, M., Strack, R., Lasse Lueth, K. and Bolle, M. (2015), “Man and Machine in Industry 4.0: How Will Technology Transform the Industrial Workforce Through 2025?”, Consulting Group, Boston, MA, September, available at: http://image-src.bcg.com/Images/BCG_ Man_and_Machine_in_Industry_4_0_Sep_2015_tcm9-61676.pdf

180.Low, S. P., Gao, S., & Ng, E. W. L. (2022), “Future-ready project and facility management graduates in Singapore for industry 4.0: Transforming mindsets and competencies”, *Engineering, Construction and Architectural Management*, Vol.28, No.1, pp. 270-90

181.Lu, S., Xu, C., Zhong, R. Y., & Wang, L. (2017), “A RFID-enabled positioning system in automated guided vehicle for smart factories”, *Journal of Manufacturing Systems*, Vol. *44*, Article No. 179-190

182.Luthra, S., & Mangla, S. K. (2018), “Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies”, *Process Safety and Environmental Protection*, Vol. 117, pp. 168-179

183.Luthra, S. and Mangla, S.K. (2018), “When strategies matter: Adoption of sustainable supply chain management practices in an emerging economy’s context”*Resources, Conservation and Recycling*, Vol. 138, pp. 194-206

184.Luo, Z., Dubey, R., Papadopoulos, T., Hazen, B. and Roubaud, D. (2018), “Explaining environmental sustainability in supply chains using graph theory” *Computational Economics*, Vol. 52, No. 4, pp. 1257-1275.

185.Luna, J.L.M., Ayerbe, C.G and Torres, P.R. (2011), “Barriers to the Adoption of Proactive Environmental Strategies”, *Journal of Cleaner Production*, Vol.19, No.13, pp.1417–1425.

186.Lv, J., Tang, R., Jia, S., & Liu, Y. (2016), “Experimental study on energy consumption of computer numerical control machine tools”, *Journal of Cleaner Production*, Vol. 112, pp. 3864-3874.

187.Lv, Z., Guo, J., & Lv, H. (2022), “Safety poka yoke in zero-defect manufacturing based on digital twins”, *IEEE transactions on industrial informatics*, Vol.19, No.2, pp. 1176-84.

188.Macher, J. T. and Mowery, D.C. (2008), “Innovation in Global Industries: U.S. Firms Competing in a New World. Washington”, *DC: National Research Council.*

189.Machado, C.G., Winroth, M.P. ,Silva, E.H. (2020) Sustainable manufacturing in Industry 4.0: an emerging research agenda, International Journal of Production Research, Vol. 58, No.5, pp. 1462-1484.

190.Malik, A. A., Masood, T., & Bilberg, A. (2020), "Virtual reality in manufacturing: immersive and collaborative artificial-reality in design of human-robot workspace", *International Journal of Computer Integrated Manufacturing*, Vol. *33*, No.1, pp. 22-37.

191.Mansouri, S. A., Ahmarinejad, A., Nematbakhsh, E., Javadi, M. S., Nezhad, A. E., & Catalão, J. P. (2022), "A sustainable framework for multi-microgrids energy management in automated distribution network by considering smart homes and high penetration of renewable energy resources", *Energy*, Vol.*245,* Article No. 123228.

192.Marsh, J. L., Soroka, A. J., Davies, P., Lynch, J., & Eyers, D. (2014), "Challenges to sustainable Manufacturing Resource Planning implementation in SMEs: An exploratory study", *KES Trans. Sustain. Des. Manuf*, Vol.1, No.1, pp. 291-302.

193.Martinsen, K. (2020), "Cyber-Physical Learning Factory", NTNU, https://www.ntnu.edu/ivb/learning-factory, accessed on 20th March 2020.

194.Mathew, M., Chakrabortty, R. K., & Ryan, M. J. (2020), "A novel approach integrating AHP and TOPSIS under spherical fuzzy sets for advanced manufacturing system selection", *Engineering Applications of Artificial Intelligence*, Vol. 96, Article No. 103988.

195.Mathew, A. (2013), "The future aspects in manufacturing industries", *International Journal of Scientific and Research Publications*, Vol. 3, No. 11, ISSN 2250-3153.

196.Mechling, G.W., Pearce, J.W. and Busbin, J.W. (1995), "Exploiting AMTS in small manufacturing firms for global competitiveness", *International Journal of Operations & Production Management,* Vol. 15, No. 2, pp. 61-76.

197.Mishra, R., Singh, R. K., & Papadopoulos, T. (2022), "Linking Digital Orientation and Data-Driven Innovations: A SAP–LAP Linkage Framework and Research Propositions", *IEEE Transactions on Engineering Management*, pp. 1-13.

198.Meyer, G. G., Wortmann, J. C., & Szirbik, N. B. (2011). Production monitoring and control with intelligent products. *International Journal of Production Research*, *49*(5), 1303-1317.

199.Mittal, V. K. andSangwan, K.S. (2011), "Development of an Interpretive Structural Model of Obstacles to Environmentally Conscious Technology Adoption in Indian Industry", *In Glocalized Solutions for Sustainability in Manufacturing: Proceedings of the 18th CIRP International Conference on Life Cycle Engineering (LCE 2011*), May 2–4.

200.Mittal, V. K., Sangwan, K.S., Herrmann, C. and Egede,P. (2013), "Comparison of Drivers and Barriers to Green Manufacturing: A Case of India and Germany", *In Re-engineering*

Manufacturing for Sustainability: Proceedings of the 20th CIRP International Conference on Life Cycle Engineering (LCE 2013), Singapore, April 17–19.

201.Mitchell, C.L., (2006), "Beyond barriers: examining root causes behind commonly cited Cleaner Production barriers in Vietnam", *Journal of Cleaner Production,* Vol.14, pp.1576 - 1585.

202.Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018), "The industrial management of SMEs in the era of Industry 4.0", *International journal of production research,* Vol. *56*, No.3, pp.1118-1136.

203.Mohan, M., Gandhi, O.P. and Agrawal, V.P. (2003), "Systems modelling of a coal-based steam power plant ", Proceedings of the Institution of Mechanical Engineers: *Part A, Journal of Power and Energy,* Vol. 217, No.3, pp. 259-277.

204.Mondal, A. S., Mukhopadhyay, A., & Chattopadhyay, S. (2022), "Machine learning-driven automatic storage space recommendation for object-based cloud storage system", *Complex & Intelligent Systems,* Vol.*8*, No.1, pp. 489-505.

205.Monge, C. A. M., Rao, S. S., Gonzalez, M. E., & Sohal, A. S. (2006), "Performance measurement of AMTS: a cross-regional study", *Benchmarking: An International Journal,* Vol. 13, No. 1/2, pp. 135-146.

206.Monostori, L., Kádár, B., Bauernhansl, T., Kondoh, S., Kumara, S., Reinhart, G., ... & Ueda, K. (2016), "Cyber-physical systems in manufacturing", *Cirp Annals*, Vol. *65*, No.2, pp. 621-641.

207.Monroy, C. R., Nasiri, A., & Peláez, M. Á. (2013), "Activity based costing, time-driven activity based costing and lean accounting: Differences among three accounting systems' approach to manufacturing", In *Annals of Industrial Engineering 2012* (pp. 11-17). Springer, London.

208.Moors, E.H.M., Mulder, K.F. and Vergragt, P.J. (2005), "Towards Cleaner Production: Barriers and Strategies in the Base Metals Producing Industry", *Journal of Cleaner Production,* Vol.13, No.7, pp. 657–668.

209.Mosterman, P.J. and Zander, J. (2016), "Industry 4.0 as a cyber-physical system study", Software & Systems Modeling, Vol. 15 No. 1, pp. 17-29.

210.Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022), "Manufacturing personnel task allocation taking into consideration skills and remote guidance based on augmented reality and intelligent decision making", *International Journal of Computer Integrated Manufacturing,* Vol.36, No.1, pp. 70-85.

211.Moyano-Fuentes, J., Sacristán-Díaz, M., & Garrido-Vega, P. (2016), "Improving supply chain responsiveness through advanced manufacturing technology: the mediating role of internal and external integration", *Production Planning & Control,* Vol. *27,* No.9, pp. 686-697.

212.Mudgal, R.K., Shankar, R., Talib, P. and Raj T.(2010), "Modeling the barriers of green supply chainpractices: an Indian perspective "*International Journal of Logistics Systems and Management,*Vol. 7, No.1, pp.81–107.

213.Muduli, K., Govindan, K., Barve, A., Kannan, D. and Geng, Y. (2013), "Role of behavioural factors in green supply chain management implementation in Indian mining industries", *Resources, Conservation and Recycling,* Vol.76, pp.50-60.

214.Muduli, K., K., Govindan, A.,Barve, and Geng, Y.(2013), "Barriers to Green Supply Chain Management in Indian Mining Industries: a Graph Theoretic Approach" , *Journal of Cleaner Production,* Vol.47, pp. 335–344.

215.Muller, J.M., Kiel, D. and Voigt, K. (2018), "What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability", Sustainability, doi:10.3390/su10010247.

216.Murray, A., Skene, K., & Haynes, K. (2017), "The circular economy: an interdisciplinary exploration of the concept and application in a global context", *Journal of business ethics,* Vol. 140, pp. 369-380.

217.Mwangola, W. (2018), "Conceptualizing Supply Chain Resilience: An Alternative Dynamic Capabilities Perspective", *American Journal of Management,* Vol. *18,* No.4, pp. 76-88.

218.Na-Nan, K., Pukkeeree, P., & Chaiprasit, K. (2020), "Employee engagement in small and medium-sized enterprises in Thailand: the construction and validation of a scale to measure employees", *International Journal of Quality & Reliability Management,* Vol. 37, No. 9/10, pp. 1325-43.

219.Nagy, J., Erdei, E., Olah, J. and Mate, D. (2018), "The Role and Impact of Industry 4.0 and the Internet of Things on the Business Strategy of the Value Chain-The Case of Hungary", Sustainability, Vol. 10, No.10, pp. 1-25.

220.NASSCOM (2007), "IT adoption in the Indian auto component industry", *NASSCOM Review report,* NASSCOM, New Delhi.

221.Necipoğlu, I. (2015), "Advanced Manufacturing as the key to sustainability", *Turkish Policy Quarterly,* Vol. 14, No. 2, pp. 1-16.

222.Nee, A. Y., Ong, S. K., Chryssolouris, G., & Mourtzis, D. (2012), "Augmented reality applications in design and manufacturing", *CIRP annals,* Vol. *61,* No.2, pp. 657-679.

223.NMCC and NASSCOM (2010), “A roadmap to enhance ICT adoption in the Indian manufacturing sector”, review report, *National Manufacturing Competitiveness Council, New Delhi.*

224.Oeltjenbruns, H., Kolarik, W. J., & Schnadt-Kirschner, R. (1995), “Strategic planning in manufacturing systems—AHP application to an equipment replacement decision”, *International journal of production economics*, Vol. *38*, No. 2-3, pp. 189-197.

225.Oettmeier, K., & Hofmann, E. (2017), “Additive manufacturing technology adoption: an empirical analysis of general and supply chain-related determinants”, *Journal of Business Economics*, Vol. *87*, pp. 97-124.

226.Ordoobadi, S. M., & Mulvaney, N. J. (2001), “Development of a justification tool for advanced manufacturing technologies: system-wide benefits value analysis”, *Journal of engineering and technology management*, Vol. *18*, No.2, pp. 157-184.

227.Orzes, G., Rauch, E., Bednar, S. and Poklemba, R. (2018), “Industry 4.0 implementation barriers in small and medium sized enterprises: a focus group study”, *IEEE International Conference on Industrial Engineering*, pp. 1348-52.

228.Oyekanlu, E. A., Smith, A. C., Thomas, W. P., Mulroy, G., Hitesh, D., Ramsey, M., ... & Sun, D. (2020), “A review of recent advances in automated guided vehicle technologies: Integration challenges and research areas for 5G-based smart manufacturing applications”, *IEEE access*, Vol. *8*, 202312-202353.

229.Ozkan-Ozen, Y. D., & Kazancoglu, Y. (2021), “Analysing workforce development challenges in the Industry 4.0”, *International Journal of Manpower*, Vol. *43*, No.2, pp. 310-333.

230.Pan, M., Yang, Y., Zheng, Z., & Pan, W. (2022), “Artificial Intelligence and Robotics for Prefabricated and Modular Construction: A Systematic Literature Review”, *Journal of Construction Engineering and Management*, Vol. *148*, No.9, Article No. 03122004.

231.Parent, J. D., & Lovelace, K. J. (2018), “Employee engagement, positive organizational culture and individual adaptability”, *On the Horizon*, Vol. 26, No.3, pp. 206-14.

232.Peng, T., He, Q., Zhang, Z., Wang, B., & Xu, X. (2021), “Industrial Internet-enabled Resilient Manufacturing Strategy in the Wake of COVID-19 Pandemic: A Conceptual Framework and Implementations in China”, *Chinese Journal of Mechanical Engineering*, Vol. 34, No.1, pp. 1-6.

233.Percival, J. C. (2009), “Complementarities between advanced manufacturing technologies”, *IEEE Transactions on Engineering Management*, Vol. 56, No.1, pp. 115-128.

234.Petrillo, A., Felice, F., Cioffi, R. and Zomparelli, F. (2018), “Fourth Industrial Revolution: Current Practices, Challenges and Opportunities”, *Digital Transformation in Smart Manufacturing,* DOI: 10.5772/interchpen.72304.

235. PIB (2022). https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1806925. Accessed on August 09, 2022.

236.Polzin, F., von Flotow, P. and Klerkx, L. (2016), “Addressing barriers to eco-innovation: Exploring the finance mobilisation functions of institutional innovation intermediaries”, *Technological Forecasting and Social Change*, Vol. 103, pp.34–46.

237.Porter, M. E., and J. E. Heppelmann.2014. “How Smart, Connected Products Are Transforming Competition.” Harvard Business Review, Vol. 92, No.11, pp. 64–88.

238.Priyavrat, T. (2011), “Competitive Foundry through Integration of TIPS Technology, Innovation, Product Design, and Process Systems”, Trends in Mechanical Engineering & Technology, Vol. 1, No 2 - 3.

239.Qureshi, M. N., Kumar,P. and Kumar, D. (2009), “Selection of 3PL Service Providers: A Combined Approach of AHP and Graph Theory”, *International Journal of Services Technology and Management,* Vol. 12, No.1, pp.35–60.

240.Raj, T., Shankar, R. and Suhaib, M. (2010), “GTMA-based framework for evaluating the feasibility of transition to FMS”, *Journal of Manufacturing Technology Management*, Vol.21, No.2, pp.160-187.

241.Raj, A., Dwivedi, G., Sharma, A., Jabbour, A.B. and Rajak, S. (2020), “Barriers to the adoption of industry 4.0 technologies in the manufacturing sector”, *International Journal of Production Economics*.

242.Ramdani, B., Kawalek, P. and Lorenzo, O. (2009), “Predicting SMEs’ adoption of enterprise systems”, *Journal of Enterprise Information Management,* Vol. 22, No.1/2, pp.10-24.

243.Ramos, M. E., Garza-Rodríguez, J., & Gibaja-Romero, D. E. (2022), “Automation of employment in the presence of industry 4.0: The case of Mexico”, *Technology in Society*, Vol. *68*, Article No. 101837.

244.Rao, R.V. and Gandhi, O.P. (2002), “Digraph and matrix methods for the machinability evaluation of work materials”, *International Journal of Machine Tools andManufacture,* Vol. 42, No.3, pp-321- 330.

245.Raymond, L. (2005), “Operations management and advanced manufacturing technologies in SMEs: a contingency approach”, *Journal of Manufacturing Technology Management,* Vol. 16, No.8, pp. 936-55.

246.Reddy, N. S., Ramamurthy, D. V., Padma Lalitha, M., & Prahlada Rao, K. (2021),"Integrated simultaneous scheduling of machines, automated guided vehicles and tools in multi machine flexible manufacturing system using symbiotic organisms search algorithm", *Journal of Industrial and Production Engineering,* Vol. *39,* No.4, pp. 317-339.

247.Renjen, P. (2020), "Industry 4.0: At the intersection of readiness and responsibility", *Delloite. Fonte: https://www2. deloitte. com/us/en/insights/deloitte-review/issue-22/industry-4-0-technology-manufacturingrevolution. html*.

248.Rischel, T.D. and Burns. O.M (1997), "The Impact of Technology on Small Manufacturing Firms*", Journal of Small Business Management* 35, pp. 2-10.

249.Rodrigues, D., Carvalho, P., Lima, S. R., Lima, E., & Lopes, N. V. (2022), "An IoT platform for production monitoring in the aerospace manufacturing industry", *Journal of Cleaner Production,* Vol. 368, Article No. 133264.

250.Romero, D., Bernus, P., Noran, O., Stahre, J. and Berglund, A.F (2016), "The Operator 4.0: Human Cyber-Physical Systems & Adaptive Automation towards Human-Automation Symbiosis", *Work Systems*, doi: 10.1007/978-3-319-51133-7_80.

251.Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, Å.,& Gorecky, D. (2016, October), "Towards an operator 4.0 typology: a human-centric perspective on the fourth industrial revolution technologies". In *proceedings of the international conference on computers and industrial engineering (CIE46), Tianjin, China* (pp. 29-31).

252.Rosen, D. and Lipson, Hod. (2011), "Discussion with study team on additive manufacturing", Washington, DC, June 24, 2011.

253.Rosnah, M. Y., Ahmad, M. M., & Osman, M. R. (2004), "Barriers to advanced manufacturing technologies implementation in the small and medium scales industries of a developing country", *International Journal of Engineering and Technology*, Vol. *1*, No.1, pp. 39-46

254. Saaty, T.L. (1980), "*The Analytic Hierarchy Process"*, McGraw-Hill, New York.

255.Saaty, T.L. (1990), ''How to make a decision: the analytic decision process''*, European Journal of Operational Research,* Vol. 48, pp. 9-26.

256.Saaty, T.L. (1994), "How to make a decision: the analytic hierarchy process", *Interface,* Vol. 24, No. 6, pp.19–43

257.Sacristán Díaz, M., Machuca, J. A., & Álvarez-Gil, M. J. (2003), "A view of developing patterns of investment in AMTS through empirical taxonomies: new evidence", *Journal of Operations Management,* Vol. 21, No.15, pp. 577-606.

258.Sagdic, K., Eş, I., Sitti, M., & Inci, F. (2022), "Smart materials: rational design in biosystems via artificial intelligence", *Trends in Biotechnology,* Vol. 40, No.8, pp. 987-1003.

259.Saliba, M. A., Zammit, D., & Azzopardi, S. (2017), “A study on the use of advanced manufacturing technologies by manufacturing firms in a small, geographically isolated, developed economy: the case of Malta”, *The International Journal of Advanced Manufacturing Technology*, Vol. *89*, No.9. pp. 3691-3707.

260.Sambasivarao, K. V., & Deshmukh, S. G. (1995), “Selection and implementation of advanced manufacturing technologies: classification and literature review of issues”, *International Journal of Operations & Production Management*,Vol. 15, No.10, pp. 43-62.

261. Sari, I.U., Cafer, E. and Ak, U. 2019, “Feasibility analysis of Industry 4.0 projects and an application in automotive maintenance systems”, Agile approaches for successfully managing and executing projects in the fourth industrial revolution, pp. 346-363.

262.Sarkar, B., & Bhuniya, S. (2022), “A sustainable flexible manufacturing–remanufacturing model with improved service and green investment under variable demand”, *Expert Systems With Applications*, Vol. 202, Article No. 117154.

263.Sarkis, J. (2018), “Sustainable and green supply chains: advancement through ResourcesConservation and Recycling”, *Resource Conservation and Recycling*,Vol.134, pp.1-3.

264.Sehgal, R., Gandhi, O.P. and Angra, S. (2000),“Reliability Evaluation and Selection of Rolling Element Bearings”, *Reliability Engineering and System Safety*, Vol. 68, No.1, pp. 39–52.

265.Shao, G., & Helu, M. (2020), “Framework for a digital twin in manufacturing: Scope and requirements”, *Manufacturing Letters*, Vol.24, pp. 105-107.

266.Shi, H. (2003), “Cleaner production in China , greening industrialization in transitional Asian countries: China and Vietnam”, *Lanham, MD: Lexington*, pp. 63-82.

267.Shi, H., Peng, S. Z., Liu, Y., & Zhong, P. (2008), “Barriers to the implementation of cleaner production in Chinese SMEs: government, industry and expert stakeholders’ perspectives”, *Journal of Cleaner Production*, Vol.16, No.7, pp.842–852

268.Shi, H., Peng, S.Z., Liu,Y. and Zhong, P.(2008), “Barriers to the implementation of cleaner production in Chinese SMEs: government, industry and expert stakeholders’ perspectives”, *Journal of Cleaner Production*, Vol.16,pp.842-852.

269.Shi, Z., Hou, X. and Bao, J. (2004), “Study on pursuance mechanism for cleaner production in china”, *Environmental protection*,Vol.1, No.2, pp.4-12.

270.Silva,D.A.L., Delai,I., Castro,M.A.S. and Ometto,A.R. (2013), “Quality tools applied to Cleaner Production programs: afirst approach toward a new methodology”, *Journal of Cleaner Production*, Vol. 47, pp.174-187.

271.Singh, R. K., & Gurtu, A. (2021), "Embracing advanced manufacturing technologies for performance improvement: an empirical study", *Benchmarking: An International Journal*, Vol. 29, No.6, pp. 1979-1998.

272.Singh, R. K., Garg, S. K., Deshmukh, S. G., & Kumar, M. (2007), "Modelling of critical success factors for implementation of AMTSs", *Journal of Modelling in Management,* Vol. 2, No.3, pp. 232-50.

273.Singh, R.K., Garg, S.K. and Deshmukh, S.G. (2007), "Strategy development for competitiveness: a study on Indian auto component sector", *International Journal of Productivity and Performance Management,* Vol. 56, No. 4, pp. 285-304.

274.Singh, R.K., Garg, S.K. and Deshmukh, S.G. (2006), "Strategy development by Indian SMEs in plastic sector: an empirical study", *Singapore Management Review,* Vol. 28 No. 2, pp. 65-83.

275.Singh, R.K., Garg, S.K., Deshmukh, S.G. and Kumar, M. (2007), "Modelling of critical success factors for implementation of AMTSs", *Journal of Modelling in Management*, Vol. 2 ,No. 3, pp. 232-250.

276.Singh, R.K. (2012), "Justification of coordinated supply chain in small and medium enterprises using analytic hierarchy process", *Int. J. Services Sciences,* Vol. 4, No. ¾, pp.277–293.

277.Singh, R.K. (2013), "Prioritizing the factors for coordinated supply chain using analytic hierarchy process (AHP)", *Measuring Business Excellence,* Vol. 17, No.1, pp. 80-98.

278.Singh.H and Khamba J.S (2010), "Research methodology for effective utilization of Advanced Manufacturing Technologies in Northern India manufacturing industry", *The IUP Journal of Operations Management,* Vol. 9, pp. 43-56, February 2010.

279.Sirkin, H.L., Zinser, M. and Rose, J. (2015), "Why advanced manufacturing boost productivity", *Manufacturing*, *Industrial Products & Processes*, Jan 30, 2015.

280.Sislian, L., & Jaegler, A. (2022), "Linkage of blockchain to enterprise resource planning systems for improving sustainable performance", *Business Strategy and the Environment,* Vol. 31, No.3, pp. 737-750.

281.Small, M. (1993), "Towards successful implementation of advanced manufacturing technology: a process-factors-process approach", *Ph.D. Thesis, Cleveland State University, USA, 1993.*

282.Song, M., Tao, J. and Wang, S. (2015), "FDI, technology spillovers and green innovation in China: analysis based on Data Envelopment Analysis, *Annals of Operations Research,* Vol. 228, No. 1, pp.47-64.

283.Song, M. and Wang, S. (2017), "Participation in global value chain and green technology progress: evidence from big data of Chinese enterprises", *Environmental Science and Pollution Research*, Vol. 24, No. 2, pp. 1648-1661.

284.Song, M., and Wang, S. (2018), "Market competition, green technology progress and comparative advantages in China" Management Decision, Vol. 56, No. 1, pp. 188-203.

285.Song, M., Wang, S., Jiang, Z., Yang, J. and Wang, Y. (2012), "Will environmental logistics be promoted by changing industrial structure? A quantitative analysis from 1978 to 2007 in China", *Supply Chain Management: An International Journal*, Vol. 17, No.1, pp.5-14.

286.Sony, M., & Naik, S. (2019), "Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review", *Benchmarking: An International Journal*, Vol. 27, No.7, pp. 2213-32.

287.Sony, M., & Naik, S. (2020), "Critical factors for the successful implementation of Industry 4.0: a review and future research direction", *Production Planning & Control*, Vol. 31, No.10, pp. 799-815.

288.Stentoft, J., & Rajkumar, C. (2019), "The relevance of Industry 4.0 and its relationship with moving manufacturing out, back and staying at home", *International Journal of Production Research*, Vol. 58, No.10, pp. 2953-2973.

289.Stentoft, J., Jensen, K.W., Philipsen, K. and Haug, A. (2019), "Drivers and barriers for Industry 4.0 readiness and practices: A SME perspective with empirical evidence", Proceedings of the 52nd Hawaii International Conference on System Sciences, pp. 5155-64.

290.Störmer, E., Patscha,C., Prendergast, J., Daheim, C., Rhisiart, M., Glover, P., Beck,H. (2014), "The Future of Work: Jobs and Skills in 2030",https://dera.ioe.ac.uk/19601/2/the-future-of-work-key-findings.pdf accessed on 17th March 2020.

291.Stornelli, A., Ozcan-, S., & Simms, C. (2021), "Advanced manufacturing technology adoption and innovation: A systematic literature review on barriers, enablers, and innovation types" *Research Policy*, Vol. 50, No.6, Article No. 104229.

292.Strandhagen, J. W., Buer, S. V., Semini, M., Alfnes, E., & Strandhagen, J. O. (2022), "Sustainability challenges and how Industry 4.0 technologies can address them: A case study of a shipbuilding supply chain", *Production Planning & Control*, pp. 1-16.

293.Sung, T. K. (2018), "Industry 4.0: a Korea perspective", *Technological forecasting and social change*, Vol. 132, pp. 40-45.

294.Sushil (1997), "Flexible systems management: An evolving paradigm. *Systems Research and Behavioral Science", The Official Journal of the International Federation for Systems Research*, Vol. 14, No.4, 259-275.

295.Sushil (2017), "SAP-LAP models of inquiry", Management Decision, Vol. 38 No. 5, pp. 347-353.
296.Sushil (2001), "SAP-LAP framework", *Global Journal of Flexible Systems Management*, Vol. 2, No., pp. 51-55.
297.Tegegne, D. A., Kitaw, D., & Berhan, E. (2022), "Advances in statistical quality control chart techniques and their limitations to cement industry", *Cogent Engineering*, Vol. 9, No.1, Article No. 2088463.
298.Thakkar, J., Kanda, A. and Deshmukh, S.G. (2008), "Evaluation of Buyer–supplier Relationships Using an Integrated Mathematical Approach of Interpretive Structural Modeling (ISM) and Graph Theoretic Matrix", Journal of Manufacturing Technology Management, Vol. 19, No.1, pp. 92–124.
299.Tomic, D. (2017), "The Benefits and Challenges with Implementation of Internet of Things (IoT) in Manufacturing Industry", Thesis, School Of Industrial Engineering and Management, KTH Royal Institute of Technology, pp. 1-45.
300.Tonn, B. And Martin, M. (2000), "Industrial energy efficiency decision making", *Energy Policy*, Vol.28, No.12, pp.831-843.
301.Tortorella, G. L., & Fettermann, D. (2018), "Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies", *International Journal of Production Research*, Vol. 56, No.8, pp. 2975-2987.
302.Tortorella, G., Miorando, R., Caiado, R., Nascimento, D., PortioliStaudacher, A. (2018), "The Mediating Effect of Employees' Involvement on the Relationship between Industry 4.0 and Operational Performance Improvement", *Total Quality Management & Business Excellence*, Vol.32, No.1/2, pp. 119-33.
303.Trianni, A. and Cagno, E. (2012), "dealing with barriers to energy efficiency and SMEs: Some empirical evidences", *Energy*, Vol.37, No.1, pp.494-504.
304.Turkes, M.C., Oncioiu, I., Aslam, H.D., Pantelescu, A.M., Topor, D.I. and Capusneanu, S. (2019), "Drivers and Barriers in using Industry 4.0: A perspective of SME's in Romania", Processes, doi.org/10.3390/pr7030153
305.UNEP (United Nation Environment Programme) and UNIDO (United Nation Development Programme) Guidance Manual (2004), "*How to establish and operate cleaner production centres" Vienna.*
306.Van Berkel, R. (2006), "Cleaner production and eco-efficiency initiatives in Western Australia", *Journal of Cleaner Production*, Vol.20, pp.1-15.

307.Veile, J., Kiel, D., Müller, J. and Voigt, K. (2019), "Lessons learned from Industry 4.0 implementation in the German manufacturing industry", *Journal of Manufacturing Technology Management*,doi.org/10.1108/JMTM-08-2018-0270

308.Verma, S. (2022), "Sentiment analysis of public services for smart society: Literature review and future research directions", *Government Information Quarterly*, Vol. 39, No.3.

309.Vickers, I. and Martyn, C. H. (1999), "Cleaner Production and Organisational Learning", *Technology Analysis and Strategic Management*, Vol.11, No.1, pp.75-94.

310.Vietnam Cleaner Production Centre (VNCPC), 2002, Vietnam Cleaner Production Centre's annual report, Hanoi, Vietnam.

311.Vinodh, S., Antony, J., Agrawal, R., & Douglas, J. A. (2020), "Integration of continuous improvement strategies with Industry 4.0: a systematic review and agenda for further research", *The TQM Journal*, Vol.33, No.2, pp. 441-72.

312.Vinodh, S., Shivraman, K.R. and Viswesh, S. (2012), "AHP-based lean concept in a manufacturing organization", *Journal of Manufacturing Technology Management*, Vol. 23, No.1, pp 124-136

313.Wamba, S. F., & Queiroz, M. M. (2022), "Industry 4.0 and the supply chain digitalisation: a blockchain diffusion perspective", *Production Planning & Control*, Vol. 33, No. 2-3, pp. 193-210.

314.Wang, Y. M., & Chin, K. S. (2009), "A new approach for the selection of advanced manufacturing technologies: DEA with double frontiers", *International Journal of Production Research*, Vol. 47, No.23, pp. 6663-6679.

315.Wang, S. and Song, M. (2017), "Influences of reverse outsourcing on green technological progress from the perspective of a global supply chain"*Science of the Total Environment*, Vol.595, pp.201-208.

316.Wang, L., Törngren, M., & Onori, M. (2015), "Current status and advancement of cyber-physical systems in manufacturing.", *Journal of Manufacturing Systems*, Vol. *37*, pp. 517-527.

317.Wang, L., Deng, T., Shen, Z. J. M., Hu, H., & Qi, Y. (2022), "Digital twin-driven smart supply chain", *Frontiers of Engineering Management*, Vol. 9, pp. 56-70.

318.Wang, G., Zhang, L., & Guo, J. (2022), "The impact of advanced manufacturing technology (AMTs) application on product innovation performance: a model of mediated moderated effect", *International Journal of Innovation Science*.

319.Wang, X., Chan, H. K., Yee, R. W., & Diaz-Rainey, I. (2012), "A two-stage fuzzy-AHP model for risk assessment of implementing green initiatives in the fashion supply chain", *International Journal of Production Economics*, Vol. 135, No.2, pp. 595-606.

320. Wang, M., Asian, S., Wood, L. C., & Wang, B. (2020), “Logistics innovation capability and its impacts on the supply chain risks in the Industry 4.0 era”, *Modern Supply Chain Research and Applications*, Vol. 2, No.2, pp. 83-98.
321. Weber, L. (1997), “Some reflections on barriers to the efficient use of energy”,*Energy Policy,* Vol.25, No.10, pp.833-835.
322. Westerman, G., Tannou, M., Bonnet, D., Ferrais, P., and McAfee, A. (2013), “The digital advantage: how digital leaders outperform their peers in every industry” available at https://www.capgemini.com/wpcontent/uploads/2017/07/The_Digital_Advantage__How_Digital_Leaders_Outperform_their_Peers_in_Every_Industry.pdf (Accessed August 09, 2022)
323. Wijewardhana, G. E. H., Weerabahu, S. K., Nanayakkara, J. L. D., & Samaranayake, P. (2020), “New product development process in apparel industry using Industry 4.0 technologies”, *International Journal of Productivity and Performance Management*, Vol.70, No.8, pp. 2352-73.
324. Xiang, S., Yang, J., Fan, K., & Lu, H. (2016), “Multi-machine tools volumetric error generalized modeling and Ethernet-based compensation technique”, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 230, No.5, pp. 870-882.
325. Yadav, G., Kumar, A., Luthra, S., Garza-Reyes, J. A., Kumar, V., & Batista, L. (2020), “A framework to achieve sustainability in manufacturing organisations of developing economies using industry 4.0 technologies’ enablers”, *Computers in industry*, Vol. 122, Article No. 103280.
326. Yang, P., Tao, P., Xu, P., & Gong, Y. (2018), “Bi-objective operation optimization in multi-shuttle automated storage and retrieval systems to reduce travel time and energy consumption”, *Engineering Optimization*, pp. 1-18,
327. Yin, Y., Stecke, K.E. and Li, D. (2018), “The evolution of production systems from industry 2.0 through industry 4.0”, International Journal of Production Research, Vol.56, No.1-2, pp. 848-861.
328. Yongqiang, J. (1995), “Cleaner Production at the Fuyang General Distillery in the People's Republic of China”, *UNEP Industry and Environment*, Vol.18, pp.23-26.
329. Yun, H., & Jun, M. B. (2022), “Immersive and interactive cyber-physical system (I2CPS) and virtual reality interface for human involved robotic manufacturing”, *Journal of Manufacturing Systems*, Vol. 62, pp. 234-248.
330. Yusuff, R.M., Yee, K.P. and Hashmi, M.S.J. (2008), “A preliminary study on the potential use of the analytical hierarchical process (AHP) to predict advanced manufacturing technology

(AMTs) implementation”, *Robotics and Computer Integrated Manufacturing,* Vol. 17, pp. 421-7.

331.Zafarzadeh, S., Mollanazari, M., & Khadivar, A. (2022), “University cost management by integrating activity based costing and system dynamics approach”, *Journal of Accounting Knowledge,* Vol. 13, No.1, pp. 1-30.

332.Zaim, S., Turkyilmaz, A., Acar, M.F., Al-Turki, U. and Demirel, O.F. (2012), “Maintenance strategy selection using AHP and ANP algorithms: a case study”, *Journal of Quality inMaintenance Engineering,* Vol. 18, No. 1, pp.16–29.

333.Zammuto, R.F. and O’Connor, E.J. (1992), “Gaining advanced manufacturing technologies’ benefits: the role of organizational design and culture”, *Academy of Management Review,* Vol. 17, pp. 701-28.

334.Zammuto, R.F and O’Connor, E. J. (1995), “Gaining advanced manufacturing technologies’ benefits: the role of organization design culture”, *Academy of management review,* Vol.17, No.4, pp.192:701-28.

335.Zeba, G., Dabić, M., Čičak, M., Daim, T., & Yalcin, H. (2021), “Technology mining: Artificial intelligence in manufacturing”, *Technological Forecasting and Social Change,* Vol. 171, Article No. 120971.

336.Zilahy, G. (2004), “Organisational factors determining the implementation of cleaner production measures in the corporate sector”, *Journal of Cleaner Production,* Vol.12, No.4, pp.311-319.

337.Zhang, Q., Vonderembse, M.A. and Cao, M. (2006), “Achieving flexible manufacturing competence: the roles of advanced manufacturing technology and operations improvement practices*”, International Journal of Operations & Production Management,* Vol. 26, No. 6, pp. 580-99.

338.Zhang,Y. (2015), “Partially andwholly overlapping networks: The evolutionary dynamics of social dilemmason social networks, “*Computational Economics,* Vol.46, No.1, pp.1–14.

339.Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M. (2021), “The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review”, *International Journal of Production Research,* Vol. *59,* No.6, pp. 1922-1954.

340.Zhou, H., Leong, G. K., Jonsson, P., & Sum, C. C. (2009), “A comparative study of advanced manufacturing technology and manufacturing infrastructure investments in Singapore and Sweden”, *International Journal of Production Economics,* Vol. 120, No.1, pp. 42-53.

List of Publications from the Research Work

(i) List of Publications published in International Journals

1) Bhandari, D., Singh, R. K., & Garg, S. K. (2019),"Prioritisation and evaluation of barriers intensity for implementation of cleaner technologies: Framework for sustainable production", *Resources, Conservation and Recycling*, Vol.*146*, pp156-167.

2) Bhandari, D., Singh, R. K., & Garg, S. K. (2018), "Justification of advanced manufacturing technologies for small and medium enterprises from auto component sector: AHP approach", *International Journal of Productivity and Quality Management*, Vol.*23*, No.4, pp 473-491.

(ii) List of papers presented/ published in International Conferences

1) Bhandari, D., Singh, R. K., & Garg, S. K. (2016),"Application of advanced manufacturing technologies in Indian SMEs: opportunities and challenges", *International Conference on Recent Advances in Mechanical Engineering (RAME-2016),* 14- 15 October 2016, Delhi Technological University, Delhi.

2) Bhandari, D., Singh, R. K., & Garg, S. K. (2017), "Barriers in Implementing Cleaner Technologies in Manufacturing Organisations, *International Conference on Evidence Based Management 2017 (ICEBM2017)*, 17-18 March, 2017, Bits Pilani, Rajasthan.

3) Bhandari, D., Singh, R. K., & Garg, S. K. (2018), "Developing frame work for green flexible manufacturing system",*Proceedings of GLOGIFT 17*, pp. 594-603, organized by Delhi school of Management, DTU, New Delhi and Global Institute of flexible systems Management, Dec 11-13, 2017 at Delhi school of Management, New Delhi.

4) Bhandari, D., Singh, R. K., & Garg, S. K. (2018), "Industry 4.0 based technologies for Manufacturing sector: Opportunities and Challenges", *International Conference on Digitilization and flexibility for organizational management and transformation*, Organized by Indian Institute of Management, Lucknow and Global Institute of flexible systems Management, Dec 18-20, 2018.

5) Bhandari, D., Singh, R. K., & Garg, S. K. (2018), "Study on impact of advanced manufacturing technologies on performance of manufacturing organizations", *International conference on business and management,*organized by Delhi school of management, (DTU), 29-30 March,2019.