STUDY AND ANALYSIS OF AUTOMOBILE MANUFACTURING INDUSTRY FROM CIRCULAR ECONOMY PERSPECTIVE

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by

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Syed Wasiul Hasan Rizvi

Candidate's Declaration

I, Syed Wasiul Hasan Rizvi, hereby certify that the work which is being presented in the thesis entitled "Study and Analysis of Automobile Manufacturing Industry from Circular Economy Perspective" in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy, submitted in the Department of Mechanical Engineering, Delhi Technological University, is an authentic record of my own work carried out during the period from July, 2018 to April, 2024 under the supervision of Dr Saurabh Agrawal and Prof Qasim Murtaza.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other institute.

Candidate's Signature

This is to certify that the student has incorporated all the corrections suggested by the examiners in the thesis and the statement made by the candidate is correct to the best of our knowledge.

Signature of the Supervisor **Signature of the External examiner**

CERTIFICATE BY THE SUPERVISOR

Certified that Syed Wasiul Hasan Rizvi (2k18/PHDME/21) has carried out his research work presented in the thesis entitled "Study and Analysis of Automobile Manufacturing Industry from Circular Economy Perspective" for the award of Doctor of Philosophy from the Department of Mechanical Engineering, Delhi Technological University, Delhi under our supervision. The thesis embodies results of the original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/institution.

Supervisor **Co-Supervisor**

ABSTRACT

With the fast-technological development in the recent past, automobile sector is continually adding to the stockpiles of discarded vehicles not only in developed but in developing parts of the world too. To overcome the problem of scarcity of presently available resources in future, the optimal strategy, emerging under the banner of 'Circular Economy (CE)', would be to keep the product-related resources such as material/energy etc., always in circulation' so that the 'waste' is either eliminated or at least is minimized. As some of the industries have already started practicing it at the global level, the underlying idea behind CE is to create products which are durable, easy to reuse, remanufacture or recycle and at the same time profitable. In the present research work, in all, there were five studies. The first one made an attempt, through a content-based systematic literature review, to seek an answer to the research question: 'Has the CE and Reversed Supply Chain Logistics (RSCL) nexus changed significantly under the impact of the IT tools and their applications?' Spanning over sixty-three data sets, the analysis was undertaken in terms of such features as data source, latency, data fields, work typography and the employed research tools. In the last five years or so, how the status of the CE-RSCL system has emerged under the shadow of the recent developments in the IT tools is discussed. Finally, conclusions indicating research gaps are drawn and directions for future research are portrayed. The second study explored the research problem: 'Have CE and its respective components' applications impacted significantly the automobile sector and what is the future scope of research in the concerned fields'. The literature spanned over around a decade containing a total number of 163 research papers was reviewed Computations were made to know in what proportions the specific 'characteristics' of different structured 'categories' contributed to the reviewed matter. The thematic contents included CE and its components, CE-Information Technology nexus, CE-automobile sector, and End-of-Life Vehicle (ELV) concept and CE. Based on the review, research gaps and the challenges ahead are demarcated, conclusions drawn and the future scope discussed. The third investigation involved integration of circular economy and Industry 4.0 components like blockchain technology that results in a faster induction of 'circularity' and leads to new strategies on resource utilization, making the world more sustainable. It is a 'key-enabler' in meeting circularity challenges of the future. The literature pertaining to the blockchain-based exploration revealed research gaps in a yet unexplored area of how 'circularity' building gets impacted by blockchain, especially in the Indian auto sector. Moreover, non-availability of its evaluation tool also necessitated the present research. The main objective was to explore, from the auto stakeholders' perception viewpoints, the potential of the application of blockchain technology with special reference to the issue of 'sustainability and circularity' in the Indian context. The study involved a literature search, building a new circular economy-based blockchain model for the auto industry, and, finally, a case study in which the hypotheses about circularity and blockchain technology nexus impacts on the Indian auto industry were structured and tested through a research instrument, designed and sent to 45 auto stakeholders for evaluation of the said nexus. The data analyzed through the Best-Worst method revealed the 'potential' (weight: 0.393) and 'application' (weight: 0.262) impacts on CE are the most important yardsticks. The proposed model appears to be more reliable and secure and might help the managers

of auto firms in forging new circularity-based strategies to exploit I4.0 efficiently. The fourth investigation was undertaken in light of the recent emergence of Industry 4.0 and the circular economy paradigm which significantly influenced various manufacturing sectors, including the automotive industry. These developments pose new challenges and issues in creating a digital and sustainable future. In response, this study was conducted to address the research gaps in the perception-based investigations, specifically in the context of the Indian automotive industry. The study explored the impacts of the circular economy-Industry 4.0 nexus on the Indian automotive industry from the perspectives of stakeholders: 98 manufacturers and 294 end-users. Perception data were collected through a structured questionnaire and subjected to statistical analysis using factor analysis (both exploratory and confirmatory) to obtain the best-fit model. The findings indicated that manufacturers recognized the potential impact of the circular economy-Industry 4.0 nexus on waste reduction, post-consumption product management, and asset analysis. On the other hand, end-users perceived that new strategies and machine tool-related aspects are best implemented through Industry 4.0 technologies. Additionally, the study applied the technology-acceptance model (TAM) to bridge the research gap and discussed other enabling factors of the circular economy-Industry 4.0 impacts in the automotive industry. The novelty of this work lay in the first-time application of TAM in the Indian automotive field. The study aimed to identify Industry 4.0-application factors affecting operational efficiency in the circular economy-oriented automotive industry, thereby aiding policy planners and managers in developing appropriate CE strategies for the digital manufacturing world of tomorrow. Finally, the fifth and the last study examines the management of vehicular waste returns in the rapidly growing Indian automotive industry. Perspectives from 96 manufacturers and 294 end-users were analyzed using exploratory and confirmatory factor analyses, along with cluster analysis. The findings provide unique insights into returns and recovery management, contributing to the understanding of environmental sustainability and the circular economy. With implications for the eco-friendly automotive sector, particularly in India, this research advances knowledge in returns and recovery management, promoting environmental sustainability in the industry. The end of the thesis presents the summarised version of the present research work through a flow diagram illustrating an overall pictorial relationship of the five investigations constituting the thesis work.

LIST OF PUBLICATIONS

SNo	*Papers*	*Journal/Conference*	*Remarks*	*Impact Factor*	*Status*
1	Circular Economy under the Impact of IT Tools: A Content based Review	International Journal of Sustainable Engineering (Taylor & Francis)	ESCI Journal	3.7	Published
2	Circularity issues and blockchain technology in the auto industry	Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 44:3 7132-7144 (Taylor & Francis)	SCI Journal	2.9	Published
3	Automotive industry and industry 4.0-Circular economy nexus through the consumers' and manufacturers' perspectives: A case study	Renewable and Sustainable Energy Reviews 183 113517 (Elsevier)	SCIE Journal	15.9	Published
4	Design of circular economy-driven returns and recovery management system in the Indian automotive industry: a case study from stakeholders' perspectives	Renewable and Sustainable Energy Reviews (Elsevier)	SCIE, SSCIE Journal	15.9	Submitted
5	The metamorphosis of the Automotive Industry; The Symphony of Circular Economy and the Enchantment of the Industry 4.0	3rd IEOM Indian International Conference on Industrial Engineering and Operations Management, New Delhi, India, November 2-4, 2023	Indexed in IEOM Index, Google Scholar and EBSCO	-	Accepted & presented
6	Developing a circulatory index for the Indian automotive industry: pros & cons, presented at 2nd International Conference	2nd International Conference on Industrial and Manufacturing Systems (ICIMS)	Punjab Engineering College,	-	Published & presented

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SNo	*Papers*	*Journal/Conference*	*Remarks*	*Impact Factor*	*Status*
	on Industrial and Manufacturing Systems, 11-19th Nov 2021.		Chandigarh (11-19th Nov 2021)		
7	Circular economy strategies for the Indian automotive industry coupled with Industry 4.0: The policies in the offing	2nd International Conference on Industrial and Manufacturing Systems (ICIMS)	Punjab Engineering College, Chandigarh (11-19th Nov 2021)	-	Published & presented
8	Digital Supply Chain in Rural Markets with Special Reference to Indian Context: An Overview	DSCM2024: Edited Book: Digital Supply Chain Management: Flexibility and Emerging Perspectives (Springer)	Scopus Indexed		Accepted
9	Unravelling the Potential of the Circular Economy to Propel Environmental Sustainability in the Automobile Sector: An Investigative Review	Journal of Supply Chain Management (Wiley)	SSCI Journal	10.6	Submitted

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LIST OF SYMBOLS

Symbol	Meaning	Symbol	Meaning
AGFI	Adjusted GFI	EoL	End of Life
AI	Artificial Intelligence	FA	Factor Analysis
AM	Additive Manufacturing	GFI	Goodness of Fit Index
AVE	Average Variance Extracted	I4.0	Industry 4.0
BDA	Big Data Analytics	IoT	Internet of Things
BT	Blockchain technology	KMO	Kaiser-Meyer-Olkin
CE	Circular Economy	MI	Modification Indices
CFA	Confirmatory Factor Analysis	ML	Machine Learning
CFI	Comparative Fit Index	MLE	Maximum Likelihood Estimation
CLD	Causal Loop Diagram	OEE	Overall Equipment Effectiveness
CV	Correlation Values	PCA	Principal Component Analysis
CVT	Convergent Validity Test	RFID	Radio Frequency Identification
CMIN	Chi-square	RDBMS	Relational Data Base Management System
CR	Composite Reliability	RMSEA	Root Mean Error of Approximation
EEA	European Environment Agency	SRMR	Standardised RMS-Residual
EFA	Exploratory Factor Analysis		

CHAPTER I

INTRODUCTION

1.1 Background

When a consumer uses a product infrequently or discards it because it has worn out, at least some of the material/energy that went into making the product gets wasted (Hannon *et al.*, 2016). Hewlett Packard Enterprise Financial Services (HPEFS) indicated that what is procured by it is remarketed to the extent of 89%, while recycling is 11% and e-waste is only to the extent of 4% and these data illustrated the success story of the concept of CE, the circular economy (HPE FS, 2019). Agrawal, Singh, & Murtaza (2018) in their case study of electronics manufacturer based in North India identified new challenges in managing product returns due to the changed business environment. To overcome the problem of scarcity in future, the optimal strategy would be to keep the product-related resources such as material/energy always in 'circulation' so that the 'waste' is either eliminated or at least it is minimized, this strategy being termed as 'Circular Economy (CE)'. Normally, companies do not bother today about what would be the ultimate fate of their products after they are procured by the end-users. A manufacturer may keep a policy of giving its customers rebates for returning end-of-life parts/products/mechanical components so that the manufacturer might be able either to refurbish them for resale at a lower price or entirely dismantle them for the purpose of recycling.

According to a recent research, each year some $2.6 trillion worth of material in fast-moving consumer goods, 80 percent of the material value is thrown away and never recovered (Hannon *et al.*, 2016). As reported in literature (Govindan & Hasanagic, 2018) by 2050, the demand for natural resources is expected to get tripled indicating thereby the exceeding importance of either elimination or minimization of waste which is the primary target of CE. In Europe, it is estimated that the net benefit of applying circular-economy principles could be as much as €1.8 trillion annually by 2030 (Manyika *et al.*, 2015). It was also predicted that by 2020, up to 50 billion connected devices would be present in our technological world (Morlet *et al.*, 2016). The firms that successfully design products from the 'circular economy' viewpoint would be of considerable value and would create everlasting and rewarding relationships with customers.

1.2 Circular economy (CE)

For the past century, companies have been constantly making efforts for developing goods and services so as to earn more and more profits. One of the important dimensions of this strategy could be traced in terms of the 'waste' resulting from the stuff we use and consume. Examples of such usable items or consumables include products, materials, and energy that never came back to the original manufacturer or supplier of the entities. When the end-users consume a product throw it away because of its wear and tear, at least some of the material or energy that went into making the product gets wasted (Hannon *et al* (2016). Such events eventually result in the evolution of the problem of resource-scarcity in future. In order to handle such problems, the optimal strategy would be to let the product-related resources such as material, energy etc. always in 'circulation' so that the 'waste' would be either eliminated or at least minimized. Such strategy of waste management is termed as 'circular economy (CE)'. According to Hannon, Kuhlmann, & Thaidigsmann (2016), every year, 80% of about $2.6 trillion of material value consumed in goods gets wasted and remains unrecovered. By 2050, it is predicted that resource demand might get tripled (Govindan & Hasanagic, 2018). Such developments necessitate concerted efforts to be made by the future researchers for CE and its applications. Proceeding in this direction, as a practical example, in Europe, approximately the net benefit of applying CE principles could be as much as €1.8 trillion annually by 2030 (Manyika *et al.*, 2015). Presently, it is observed that this technological world, while travelling through the corridors of newer developments, has been encountering a variety of new challenges. One of these problems, which is particularly serious, is the "scarcity of resources," which is becoming worse with the technological developments getting advanced day by day. Everyone in the world, whether a consumer or a producer, has been consuming some percentage of the valuable and rare resources, making future of humanity increasingly unsustainable. Geissdoerfer (2018) observed that CE is emerging as a tool for achieving sustainable development, which means meeting the present needs of humanity without harming the interests of future generations. CE can offer either a comprehensive or partial solution to the challenges of sustainable development (Geissdoerfer *et al*., 2017). Regarding manufacturing activities, Lieder and Rashid (2016) reviewed the role of CE in waste management, and Agarwal, Singh and Murtaza (2018) discussed the readiness of the Indian manufacturing sector for CE applications. Alcayaga *et al*. (2019) noted that the tools of the digital era could contribute to enhancing various aspects of CE, including recycling, reusing, and remanufacturing. In general, from the literature till date, it appears that CE spans over its components like: Reuse, Repair, Remanufacturing, Recycling, Refurbishing and Remarketing etc. The concept of multiple loops in CE in this context was reported in literature (circularise.com) where, there are three kinds of CE loops:

(a) the short loops which include components such as R0-Refuse, R1-Rethink, R2-Reduce.

(b) medium loops which include R3-Reuse, R4-Repair, R5-Refurbish, R6-Re manufacture, and R7-Re-purpose and

(c) long loops which include R8-Recycle and R9-Recover.

Therefore, it is observed that as a matter of fact, CE is a model of resource production and consumption in an economy which includes sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for the longest time. To overcome the global challenges of climate change, biodiversity loss, waste, and pollution, this concept would be ideal by laying emphasis on the design-based implementation of the three base principles of the model. The three main principles required for the transformation to CE are as follows: a) designing out waste and pollution, b) keep on using the products and materials without wasting any, and regenerating the natural systems. To be pragmatic, only 9% of the world's economy is circular, it has been calculated that the opportunity to profit from the conversion of the remaining 91% is estimated to be $4.5 trillion. Moreover, CE typically employs a more significant number of people than the statistics show – in the Turku sector alone, it is estimated that there are up to 700 circular economy actors.
According to the European Parliament's 2020 circular economy plan, the system would be able to generate about 700,000 jobs just within the European Union by 2030 (Dhaliwal, 2023). It can be elucidated in the case of CE and waste management that the waste management can be considered as the final phase in the process of utilizing materials in the most efficient manner possible. In fact, it is essentially where the loop closes. On the contrary, it is evident that circular waste management systems form the crux of CE, the primary difference being how materials are managed post-use. Another framework within the CE literature has emerged in the form of biological and technical cycles, it is reported that the biological cycle refers to processes where materials are biodegraded and safely returned to the Earth. Biologically-based materials are designed to be restored into natural systems and regenerated to provide renewable resources. Thus, all materials used are essentially on loan from nature, and biobased materials eventually return to nature's biochemical cycles. Recently, the Ellen MacArthur Foundation has, in its own framework, separated circular economy into biological and technical loops. In the biological loop, biologically-based biodegradable raw materials obtained from nature cycle in the system. Technical cycles encompass man-made materials, substances hazardous to the environment and rare metals used for example in electronics. Biological cycles enable the recycling of bio-based material back into the manufacturing processes and into new applications. In addition, the biogas generated in the process can be used in energy production. As per circular economic thinking, all the materials we are using are essentially only on loan from nature and eventually the biobased materials will be restored to nature. The materials in the technical cycle originated from human activity and were created as raw materials for different commodities. The raw materials for the original substances were obtained from nature, however, through processing they have acquired such a form that they can no longer be returned into nature. These substances should circulate as efficiently as possible, to limit the amount of new raw materials being collected from nature. For example, nowadays rare metals are being extracted from electronics dumped in landfills. It would be preferable for these metals to circulate without ever

ending up in landfills. Technical materials can be reused directly or they can be processed further and turned into raw materials. The key is, however, to separate technological cycles from nature in order to avoid problem, such as the entire biosphere becoming polluted with microplastics. Inside every machine, product, or process are countless essential components that contribute to carbon emissions for their entire lifespan. But those parts and materials can find their way into other uses instead of being discarded. The Circular Economy (CE) economic model outlines how we can reduce the number of materials and resources for anything we build or manufacture. But it doesn't have to be this way. Circular economy redefines what is considered waste, with hallmark processes that could not only reduce waste produced, but also diminish the quantity of virgin materials we need. It can also address 70% of greenhouse gas emissions globally. With so many benefits, policymakers and businesses are working to increase resource recovery, extend the life of products, and shift away from the cheapest waste-management solutions such as landfill and incineration. Also, in the context of CE, Life Cycle Assessment (LCA) is another term which is commonly elaborated in literature so as to promote sustainability and reduce environmental impacts. To assess the environmental impacts of a product, process, or service throughout its entire life cycle, LCA methodology is used. This starts right from the raw material extraction, to production and use, until the disposal or recycling (Ellen McArthur Foundation, 2012). LCA helps in identifying the areas where enhancements can be made to reduce the environmental footprints. It is a treasured tool for executing and assessing the CE strategies. LCA helps in designing products and processes by providing a comprehensive view of the environmental impacts which align with CE principles, viz., reducing waste, reusing materials, and recycling. Thus, it makes sure that the CE initiatives are genuinely sustainable and do not shift the environmental burdens from one stage of the life cycle to another.

1.3 Automotive industry

Among the varieties of daily-use products, the automotive industry products like cars, scooters, motorbikes and other kinds of two-wheelers and four-wheelers have already acquired the status of daily-use products both in developed as well as in developing parts of the world. This results in huge pile-up wastes at the global level. Accordingly, it appears that CE can play a very important role in the automobile industry also by focusing on waste management, especially when it was noted that, as stated earlier, material valued at about $2.6 trillion (or about 80% of the material value) is wasted every year in the consumer goods industry (Hannon *et al*., 2016). Thus, a wide range of materials, including steels, plastics, glassware, rubbers, mechanical and electrical components, etc., can be saved and recovered through the implementation of the Circular Economy (CE) in the automotive industry (Pomili *et al*., 2020). It is worth noting that in today's digital era, the effectiveness of CE and its operation would largely depend on the use of IT tools. Laliberte (2019) has correctly recognized that it's high time to accelerate the adoption of the CE culture within organizations by digitizing it. This approach contributes to the reduction or elimination of e-waste, as exemplified by the experience of Hewlett Packard (HP). In the current technology-driven world, digitization has been playing a significant role in ushering in the Fourth Industrial Revolution (I4.0). However, neither academia nor industry has provided sufficient guidelines for evaluating the evolving digitized industrial culture that relies on IT tools (Gigauri, 2021). It's projected that digitizing logistics processes will yield around 1.5 trillion USD by 2025 (WEF, 2016). I4.0-driven digitization, facilitates the rapid development of the CE, which aims to keep resources in constant circulation and promotes sustainable development. The interface between I4.0 and CE, emerging as a 'focus area' (Okorie *et al*. 2018b), enables the formulation of strategies for utilizing new natural resources, enhancing productivity, and fostering sustainability. Presently, the automotive industry is experiencing rapid growth in both developed and developing regions, emerging as the fastest-expanding sector (Bhasker *et al*., 2020). During the Covid-19 period there was a shortage of chips production and due to this problem around 11.3 million vehicles were cut from the global market in 2021 in USA. However, the sales at the global level again emerged to be growing after 2022. There was a forecast of 66.7 million units' sales in the year 2021 and that was to be growing in the years to come (Statista, 2023). Of late, a new development in automotive industry emerged in the form of electric vehicles. Its global share in the market reached 4.2% in 2021 and this is expected to go to 22.6% by 2028. Such a rise in demand is based on the current trends of the needs of eco-friendly vehicles, increasing facilities of charging stations, governmental supports and, of course, the technological advancements in making the vehicles smarter. Such a global development has led USA to set a target of 50% all cars to be sold to be electric by 2030 in the market and to support this endeavour an investment of $7.5 billion in the charging infrastructure status would be undertaken by the US Government. (Bing, 2023). So far as the Indian automotive industry is concerned it might be noted that in India, it is anticipated that the automotive industry will surpass a market value of US $250 to 280 billion (equivalent to approximately 20 trillion Indian Rupees) by 2026. This growth is expected to be further propelled by the introduction of electric vehicles, such as e-bikes and smart cars, which are poised to gain significant traction in the market (IBEF, 2022). It was recently reported that India is passing through its infancy stage in the electric vehicles market as its share was only 0.5% in 2020. However, with the increasing environmental concern and provision of the Governmental support in terms of the infrastructural and incentive-based promises, India has set an 'ambitious target of achieving 30% EV penetration by 2030' (Bing, 2023).

With the fast-expanding concern for the environment and ecologically sound tomorrow, the global awakening has recently generated huge pressures on the automotive industry both from the governing systems as well as the social systems. As a result, such factors as global CO_2 emissions, damage to natural eco-systems, disposal of the non-biodegradable wastes, and resource-intensive production systems have to be accepted as newer challenges by the fast-expanding horizon of the automotive industry. To be specific, around 18% of CO_2 emission is being contributed by the automotive vehicles. The modern electric vehicles are responsible for major portion of graphite resulting in crop-damages and soil pollution etc. The non-biodegradable wastes like plastics etc. used in production as well as consumption are exceedingly big problem-creators around the present societies. It was reported that 3.1 million tons of plastics as a waste generated from vehicles were dumped in Asian parts by the USA, Europe and Japan collectively, giving rise to the problems of landfills, water and other kinds of pollution for the society. Also, this automotive industry consumes the resources intensively. For example, the industry consumed 2 billion litres of water and produced 1 million tons of CO2 in UK alone during the manufacturing of cars and components (InMotion Ventures, 2021). Whereas, a car, in general, contains 1.4 tonnes of materials and usually only a part of materials is recycled, thereby indicating the necessity of the CE applications for a more sustainable future in the automotive industry of tomorrow. In order to effectuate the sustainability to the automotive industry varieties of doors would have to be knocked at. Digitization, lowering of the emissions and human-vehicle system safety from ergonomics viewpoint are some directions for the future researchers in the field. Already some efforts are visible on the sustainability front. For example, modern vehicles are being redesigned to make them lighter in weight. Thus, Volkswagen use renewable materials (natural fibres, flax, cotton, wood, cellulose, etc in its car-components. In fact, it might be observed that to make the automotive industry sustainable in future, a holistic approach would have to be executed in terms of redesigning it to make it eco-friendly, environmentally viable and human-centric.

1.4 The emerging digital era

The data pertaining to CE system appears to be huge and therefore the success of CE and its operation would primarily depend on the extent to which IT tools are employed. Laliberte (2019) has truly observed that, in light of the HP experience, this is high time to accelerate the CE culture for the enterprises by way of getting it transformed digitally and thereby add to the e-waste minimization or its elimination altogether. Like any other product, the automotive products also contribute to the waste in a huge way and present work is planned to study the CE-IT based applications in the automotives sector with special reference to the Indian scene.

1.5 Issues pertaining to the automotive industry-CE-IT nexus

The present research involved exploration of the key issues related to circular economy (CE) and its components, CE in the context of the automotive industry, and impact of the IT tools on CE-automotive industry across the world. The research, specifically addressed the issues pertaining to the explorations on the impacts of the CE developments, CE-IT tools like IoT, RFID, Big Data etc. on the automotive industry, Blockchain Technology (BT), and finally, the returns and recovery management (RRM) system within the context of the CE, focussing on the automotive industry.

1.6 Research motivation

The overall technological developments, both at the global as well as at the National levels, is resulting in attracting more people to the urban settings of population. The main reason behind such a scenario happens to be the provision of more sustainable living environment in the urban locations. This trend is expected to continually become more prominent in the days ahead. As a consequence, more and more resources would be eaten up by the products manufactured and consumed by the more sustainable society in future. That poses a big challenge to the future technology planners demanding more focussed explorations on the applications of the emerging tools of circular economy (CE). Since the last one decade or so, many researchers have worked on CE, However, the recent emergence of the Industry 4.0 era needs extensive work on CE, particularly, in the widely encountered fields of application like automotive industry that would prove to be a critical driver of the sustainable society of the future. Such an industry has become the need of the hour for all the people, but this is also a fact that the auto sector alone generates a huge quantity of wastes resulting in a serious environmental problem for the society. Manufacturing demands energy, usage consumes energy, disposal needs energy, recycling needs energy material y and, finally, remanufacturing demands energy. Similarly, the larger the quanta of auto production, the higher the material resource depletion, Thus, policy-planners of future energy and material-resource managers of tomorrow would encounter a big challenge in the days ahead, thereby needing extensive research on the topic of CE and presenting high level of motivation to the current generation of researchers in the field.

1.7 Research objectives

The present research aimed at two-pronged objectives. The first explored previously undertaken state-of-art research work critically to review how and to which extent the CE and the CE-Industry 4.0 nexus contributed to the automotive industry in getting it modernised, digitised and sustainable. The second phase of research was based on three case studies pertaining to various facets of CE and CE-I4.0 nexus in the Indian automotive industry. These investigations were planned by way of using the research gaps, as identified in the next Chapter (Chapter II) and accordingly the research objectives were defined for the present research as follows:

- To study and analyze the Indian automobile manufacturing industry from a circular economy perspective.
- To study and analyze the role of IT tools in the automobile manufacturing industry.

- To develop the models for adopting and implementing circularity concepts in the industry by way of exploration pertaining to CE-BT nexus in the automotive industry.
- To explore the circularity issues through a case study by way of by way of exploration pertaining to CE-Industry 4.0 nexus in the automotive industry.
- To develop a framework for the performance evaluation of the industry by way of exploration pertaining to Return and Recovery Management (RRM) study in the automotive industry.

Based on the above-stated research objectives, research questions (RQs) or the structured hypotheses (Hs), corresponding to each objective, were designed as follows:

- Corresponding to the CE objective the RQ is 'Have the CE and its respective components' applications impacted significantly the automobile sector and what is the future scope of research in the concerned fields?'
- Corresponding to the CE-IT tools objective the RQ is 'Has the CE and RSCL nexus changed significantly under the impact of the IT tools and their applications?'
- Corresponding to BT in automotive industry related objective, the structured hypothesis, H1, reads as 'All the considered factors related to the Blockchain Technology Potentials (BTP), Blockchain Technology Barriers (BTB), and Blockchain Technology Applications (BTA), within the CE framework have same influence on the stakeholders perceived decision making process'. The second structured hypothesis, H2, reads as 'All the three (manufacturers, dealers and end-users) Indian automotive stakeholders' perceptions about CE-BT impacts weigh equally in terms of the investigated factors.'
- Corresponding to the CE-I 4.0 related in automotive industry objective the structured hypothesis, H1, reads as 'CE execution based on the I4.0 tools is significantly affected by the perception of automotive manufacturers'. The second hypothesis, H2, reads as 'CE execution based on the I4.0 tools is significantly affected by the perception of the end-users of vehicles'
- Corresponding to the investigations on RRM related objective, the hypothesis, H1, reads as 'the perspectives of the Indian automotive industry stakeholders, the manufacturers, significantly affect the returns and recovery systems'. The second structured hypothesis, H2, reads as 'the perspectives of the Indian automotive industry stakeholders, the end-users, significantly affect the returns and recovery systems'.

Schematically, the entire plan of the research work is portrayed in Fig 1.1.

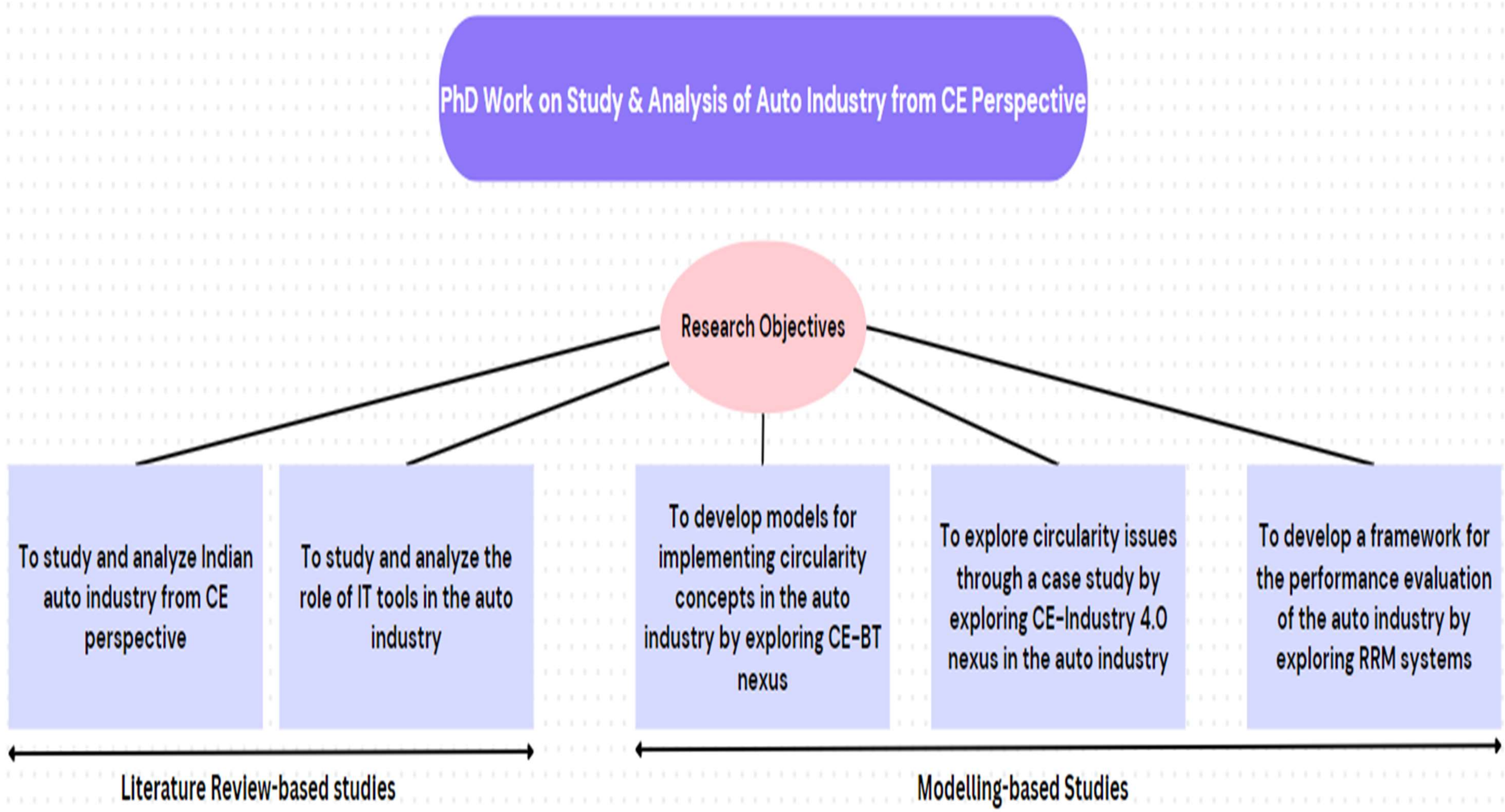


Figure 1.1 PhD work plan

1.8 Research findings

Majorly, present research contributed in terms of the following findings:

- The literature review, based on the 'content analysis' methodology, revealed 'research gaps' presented as the findings for future research and the same provided the framework for the present work.
- Meeting the first two research objectives, stated in Section 1.2 (Chapter-1), two comprehensive literature surveys were undertaken through the descriptive method and hypothesis testing as presented in Sections 2.5 & 2.6 in the next chapter (Chapter-2). It revealed, respectively the impacts of the CE and CE-IT tools on the emerging developments in the automotive industry.
- The CE-related research found that today's technological world is passing through an era which demands not only 'conservation' but also 'circulation' of resources. It appears that in case of automobiles, only developed nations have taken steps in implementing the CE applications. Thus, underdeveloped countries like India have to initiate 'remanufacturing' particularly in the field of CE-automobiles.
- Almost no or hardly few studies on CE based applications pertaining to the two-wheelers are available in literature at the global/national level. India and China are the two giant leaders in two-wheelers' industry in the world.
- Possibly, there is a need to make more efforts in future to explore some more dimensions in CE understandings, particularly from the consumer perspective point of view. Today's ongoing efforts by the researchers in the fields of CE-RSCL-DT nexus indicated that 'the potential for digital intelligence to enable a regenerative economy is promising'.
- It appears that the fourth industrial revolution that highlighted the IT tools like Big Data, 3D Printing, IoT, and Analytics etc. helped the companies in introduction of CE in their affairs. Present review of the related matter-contents indicated the infancy stages for CE-RSCL nexus as well as the emerging IT tools like Big Data analytics etc. applications implying thereby in immense scope for their development and growth in the days ahead. Also, it has been investigated that integrating the CE principles into RL processes provides environmental benefits by reducing the footprint of production processes along with the business profitability as well. As a matter of fact, RL fits into a more comprehensive and up-to-date concept of "social responsibility of logistics". This concept underlines the principles of corporate social responsibility applied to the logistics functions and the supply chain organization. However, the literature concentrating on the application of CE in the context of RL activities is fairly new and still immature. The present research purposes to fill this gap by analytically reviewing the literature focusing on the integration between CE principles and the RL process, thereby enabling circular reverse logistics. the recovery, recycling, reuse and re-manufacturing of materials that return from the consumer to the producer come under the purview of the application of CE principles in reverse logistics (RL) processes. Biancolin *et al.* (2023) evaluates whether the manufacturing sector, technology, supply chain (SC) structure, customers' preferences, and policy makers

impact the diffusion of circular RL, stressing on the strategies adopted by companies.

- This study proposes a new CE-BT model that appears to be more reliable and secure than other classical models applied to CE in the automotive sector. The study revealed that the structured hypotheses were found non-acceptable as all the three stakeholders considered, perceived 'Reuse dimension' and 'CE-BT applications' amongst the most crucial CE-BT impacts on the Indian auto industry.
- Also, the study indicated that the different criteria that were considered weighted differently as perceived by the stakeholders. This might be the first attempt of the kind in the CE-BT literature and it may help the future planners of the digitized CE induction in the Indian auto industry. Future researchers might address the issue of comparative perception of different stakeholders of the auto industry. Proposed operational model might be helpful.
- The present study revealed that the car manufacturers perception is that employing I4.0 tools may have a significant influence on asset analysis, waste reduction, and management of post-consumer products, whilst end users perceived that I4.0 might be the ideal way to execute new strategies and those using machine tools.
- The research on RRM revealed that the number of returns and recovery of the cars is providing new issues for the researchers of the future as the automotive sector is expanding day by day. With technology improvements, methods may be sought to address the issues that lead to end-users returning unneeded and used goods, minimising or eliminating the "returns" completely.
- Today, the 'recovery' of materials and 'returns' of goods via the CE component 're-use,' have arisen as a pressing requirement, both in terms of environmental protection and waste management. For sustainable resource utilization, RRM is a component of green technology in the automotive industry context.
- The findings of this research have significant implications for future policy makers and practitioners in the auto industry. The understanding of end-user perception, as explored in this study, will offer valuable insights for industry managers to effectively retain their customers in the future.
- Examining how end-users and manufacturers interpret "TOR" (Types of returns) and "IOR" (Influencers of returns) contributes not only to future planning in the auto industry but also to environmental protection, fostering a more sustainable future.

1.9 Thesis organisation

The present thesis comprises of ten chapters. Their contents are briefly described as follows:

Chapter I: Introduction: It puts forth the background of the research problems and then the research objectives are laid down, research questions are presented, hypothesis structuring is done, and then research findings are presented. Finally, the pattern of the thesis structure is portrayed.

Chapter II: Literature review: This chapter presents the literature search pertaining to the topics associated with the research issues involved in the present work. The research methodology employed for the literature review is discussed and based on the review the research gaps are identified. The chapter ends with the concluding words.

Chapter III: Research methodology: In this chapter, first, the research approach is presented. Next, methodologies for the literature survey-based studies, the 'content analysis' methodology is described. For the CE-BT nexus in the automotive industry, BWM methodology was employed and its details are presented. Next, for the CE-Industry 4.0 nexus in the automotive industry FA-based methodology was employed and detailed. Finally, for Return and Recovery Management (RRM) study in the automotive industry, the employed FA-based tools and cluster analysis are described.

Chapter IV to Chapter VIII: These five chapters respectively span over the description of the purpose, method, result and, finally, the discussion and conclusion pertaining to the five respective explorations undertaken in the present research.

Chapter IX: This chapter presents the conclusion, social impact of the main findings along with the limitations of the present research.

Finally, limitations of the research are discussed systematically. The thesis concludes with the 'references' and the 'appendices', provided at the end.

The next chapter (Chapter II) presents the review of the literature pertaining to different facets of the research undertaken in the present work.

CHAPTER II

LITERATURE REVIEW

The previous chapter (Chapter I) presented the preliminaries related to the research work undertaken whereas the review of the pertinent literature is put forth in what follows:

2.1 Introduction

Presently, under the shadow of economic and industrial development the precious reassure of available resources is depleting at an exponential rate, resulting in evolving an unsustainable world of tomorrow. All the companies of the world have been targeting to maximise their profits. In this process of development s whether economic or social or technological, we are all contributing to the generation of 'waste' of materials resources and energy. The manufacturers of goods, the consumers of goods and other end-users, all contribute to the resource-scarcity in each and every moment of their passing life-days. Recently, a new weapon to counter this situation has been evolved in the form of what is called 'circular economy'. Primarily, circular economy either eliminates waste-formation or at least it helps in minimisation of waste. This becomes possible by keeping the resources always in circulation and/or recirculation. Thus, circular economy is basically a strategy of waste management. Few years back it was predicted that by 2050, the demand of resources might get tripled. Present review made an attempt to put for the emerging concept of the circular economy and its importance in the current economic and industrial environments of the developmental economies of the world. Under the current technological development at the global level as well as at the national level, the survival of the future of humanity would be facing a highly unsustainable world of tomorrow. Under these circumstances, the future researchers would have to evolve some means and ways to keep the current treasure of resources in-tact. For this the resources would have to be kept in circulation and recirculation by adopting the strategy of the circular economy.

In the previous chapter (Chapter I), various facets of the present research are presented. In this Chapter relevant topics associated with different dimensions of the research problem are explored to review the literature related to the thematic applications which have impacted significantly the automotive industry, both at the global as well as the National levels.

2.2 Automotive industry: Global and National scene

- *Indian Auto Industry*

Today, the automotive industry happens to be the fastest-expanding industry in both the developing and developed parts of the world (Bhasker *et al*., 2020). The Indian automotive industry, by the year 2026, would be worth more than US $250 to 280 billion (around Indian Rupees 20 trillion). With the induction of electric vehicles, including e-bikes and smart cars, in the automotive market, the industry is expected to flourish exponentially in the near future (IBEF, 2022). One recent comprehensive review of the literature, based on 518 research papers on the RRM (Ambilkar *et al*., 2021), indicated the 'returns' of the products to be a critical issue due to the uncertainties involved in the related parameters. Induction of CE in the Indian automotive sector would primarily lead to material circularity, resulting in the alleviation of waste to a minimum level (SIAM, 2020). Thus, CE replaces the cradle-to-graveyard' model with the 'cradle-to-cradle' model. In the context of the Indian automotive industry, this is in conformity with Indian Government policy (GOI, 2019). Some researchers use the term '3Rs' for reduce, reuse, and recycle activities pertaining to the CE (Spilka *et al*., 2008). Since long, the necessity of governmental legislation has been felt for the success and implementation of the whole process of returns and recovery in industrial houses (e.g., Burdett, 2009). In conclusion, the analysis of the Indian automotive industry revealed that it is currently dealing with issues like the need to establish government policies regarding the recycling of vehicles and their scrap, the estimation of the Indian market's potential for CE and its component of recycling for scrap related to the automotive industry, the investigation of recycling opportunities and the adoption of CE in the automotive sector, and the introduction of innovative technologies. Also, the automotive industry's stakeholders (customers, end-users, manufacturers, etc.) participation is vital for the supply chain network of the auto industry to be successful in operation.

- *CE and the auto industry*

From the literature, it appears that CE spans over its components such as reuse, repair, remanufacturing, recycling, refurbishing and remarketing. So far as automotive sector is concerned, a very important component of CE, remanufacturing in itself is emerging to restore End of Life (EOL) products to the status of the "like new" or "better-than-new" quality form (Cao *et al.*, 2009). It was observed by Xin (2016) that with the newer technological and economy-based developments, more and more people are buying cars so that the number of scrapped automobiles is also increasing day by day. Therefore, in the field of auto parts remanufacturing, it is particularly getting more and more important to undertake more and more of the research work in the days ahead. Today, at the global level, especially in technologically advanced countries, remanufacturing is emerging in varieties of industrial sectors. For example, in electronics industries, defence production, machines and machinery fields, automobile engineering and many other areas, remanufacturing is coming up fast. At present, particularly in the auto sector, remanufacturing is getting shaped into a new kind production system in which auto remanufacturing cost, quality, time etc. might be expected to have an impact on automobile main parts remanufacturing also. It appears that in China, remanufactured industrial and consumer goods market is flourishing at a faster rate and such a development is leading to a significantly high quality of waste management strategy in the Country. According to Zhang *et al*. (2020), present status of China is described as the 'largest automobile market worldwide after years of steady growth in automobile sales and production'. They also observed that in 2018 end, number of civil motor vehicles and total resale of retails have respectively gone to 240m and 4200b Yuan and thus there would be a massive volume of auto scrap in China in the near future. According to Nieuwenhuis *et al.* (2014), the industrial sector associated with car manufacturing appears to be not very sustainable owing to its primary feature of producing cars more than what is demanded by the market. Literature on the research on the 'leagile' material shows that according to a new understanding of 'lean' and 'agile' processes, the basic problem of 'overproduction' can be minimized if not eliminated, by way of adopting a newer level of the economies of scale in manufacturing of cars. This might eventually lead to a more sustainable auto manufacturing and remanufacturing industry in future. Diaz *et al*. (2020) discuss various value-retention strategies in this regard, which they refer to as R-strategies (the 3 R's) to align an organization's objectives with UN's Sustainable Development Goals (SDGs). A recent study pertaining to the 'Remanufactured Auto Parts' (RAPs) in Japan indicated a relatively undeveloped market in Japan as compared to US where a long and successful history of RAPs was found (Matsumoto *et al.*, 2017). An analysis of the locally functioning auto parts remanufacturers in China revealed that many global players of the automobile engineering field got attracted by China and such a development led to varieties of innovation in car manufacturing technologies (Xia *et al.*, 2014). In many countries, passing through the so called 'developing' phase, like India, Brazil etc., also appear to be moving fast to acquire the status of mainstream nations in the auto sector under the banner of increased activities in 'remanufacturing' for a better sustainable future of the trade and its own people.

Some of the important findings of different authors on remanufacturing are summarized in what follows. (a) Remanufacturing strategy can alleviate the loading of the environmental burden. (Jiang *et al.*, 2018). (b) With almost no solid waste generation, huge savings (cost: 50%; energy: 60% & material: 70%) were reported under the impact of remanufacturing strategy of the CE framework. (Ramesh *et al.*, 2013). (c) Based on MCDM technique called Fuzzy TOPSIS, material performance was evaluated and thus the task of material selection during the design and development of the automobile and its parts made the remanufacturing function more feasible in practice (Zhaoanjian *et al.*, 2015). (d) In the context of the Chinese automobile manufacturing scenario, it was found that the resource efficiency got enhanced and CE philosophy got promoted as a result of the introduction of the remanufacturing culture in auto sector (Liu *et al.*, 2018). (e) How the subsidies offered to the end-users in Chinese automobile sector contributed to the recycling and remanufacturing components of the CE was investigated through the tools of system dynamics and simulation technique (Wang *et al.*, 2014).

2.3 Circular economy and emergence of Industry 4.0

The CE-IT nexus appears to be expanding day by day. A review of the recently undertaken studies involving CE applications in varieties of technological situations revealed that RFID (Radio Frequency Identification), IoT (Internet of Things), BT (Blockchain Technology) and BD (Big Data) kinds of software-based technologies are getting widely employed today. (Palmaccio, Dicuonzo & Balyaeva, 2020). Many researchers are working on exploration of CE-IT world. For example, based on 135 case studies, Pagoropoulos, Pigosso, & McAloone. (2017) identified three architectural layers having a profound impact on CE-IT nexus. In their recent work, Rizvi *et al* (2021) presented a detailed review of the topic under reference whereas Tsao (2017) experimented with the RFID in JIT (Just-in-Time) and some other studies undertook the operation of material tracking in its flow line, thereby providing means for the material recovery; a very significant function of the CE (Atzori *et al.*, 2010; Da Xu *et al.*, 2014). So far as IoT is concerned, Manyika *et al* (2015) employed it in computing systems monitoring. The RDBMS (Relative Data Base Management System) and PLM (Product Lifecycle Management) systems of IT tools were also found supporting the CE framework in real life applications (Lieder and Rashid, 2016). According to Chalkias (2019), by 2020, IoT would be a key-part of the Industry 4.0 and revenue from Big Data Analytics by 2020 would $203b at the global level whereas the artificial intelligence (AI) tools were indicated to be the promising tools of future CE applications (Weichhart *et al.*, 2016).

In terms of Big Data, Serban (2017) studied its impact on the functioning of a firm and Jain *et al* (2017) demonstrated its application in the supply chain management. For the emerging economies, it is found that Big Data is of great help to managers in terms of the reverse logistics, exchanging information for the refurbished products and ensuring easy returns (Patwa *et al.*, 2021). Big Data application in the automobile sector was studied by Ge and Jackson (2014) whereas it was also noted that CE without proper support of Big Data might not be an effective proposal (Jabbour *et al.*, 2019). To identify the products that have parts sharing less value, BT can be employed by manufacturers to achieve CE (Leng *et al.*, 2020; Kamble *et al.*, 2021a). What are the barriers in the CE-Industry 4.0 nexus was recently analyzed by Kumar *et al* (2021b) through an integrated approach using AHP and ELECTRE (ELimination Et Choice Translating REality) methods to improve the sustainability of a supply chain. A comprehensive review was presented by Nobre *et al* (2017) on the general impacts of IT on CE. Through their case study, Bressanelli *et al.* (2018) observed that IT tools-based technologies might enable us to encounter the future problems associated with the CE field. Also, CE-IT nexus developments might be expected to be helping in making the industrial houses smart in future (Lampathaki *et al.*, 2015; Weichhart *et al.*, 2016). The United Nations set the 2030 agenda for the world in terms of getting it shaped into a sustainable globe (UN, 2015) and Dantas *et al* (2020) referred to the CE-Industry 4.0 nexus that directly has a bearing on these already set SDGs of the UN.

- *CE & RSCL Nexus under the Impact of Recently Evolved IT Tools*

With the advent of computer applications in manufacturing, there has been a revolution in the offing resulting in the transformation of the whole world of production and bringing it to a single platform, more precisely miniaturization that is currently passing through its infancy stage. The concept of circular economy came much later when the digitalization was at its peak, and plenty of advance platforms were available to pursue any long-drawn task in a jiffy with maximum efficiency. For example, Ardolino *et al* (2017) discussed how the digital technologies played a key role in service transformation of industrial companies. So far as the circular economy is concerned, it is characterized as an economy that is restorative and regenerative by design and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles (MacArthur & Waughray 2016). In this system, manufacturers get the benefit of profit for selling a single product and also keeping them in circulation for a longer duration resulting in overall savings in terms of energy, materials and other resources associated with the manufacturing process. The customers also derive benefit from this system as they pay only for what is required to them. Therefore, both the sides benefit from a more active and long-term relationship. Recently, in Denmark, another offshoot of CE in the form of local circle appeared in the field of mobile repairs (Riisgaard, Mosgaard, & Zaco, 2016).

2.4 The research methodology for the literature-survey

As stated earlier in the previous chapter, in all, there are five studies planned in the present research. Each study corresponds to respectively each of the five research objectives stated in the previous Chapter (Section 1.7). The research methodology 'content analysis' was employed for the topics pertaining to the literature-based research objectives (first and second objectives). The topics covered under this head pertain to the first two research objectives. The in-depth details of this research methodology ('content analysis') is presented in the next chapter (Chapter-3). So far as the related topic of the remaining research objectives are concerned, the 'general approach' for the review was employed through surveying the published corridors of literature pertaining to various topics and sub-topics associated with the last three research objectives stated in Section 1.7. Corresponding to each of the study-problems, the literature search was made and the reviewed matter-contents explored under the respective studies are discussed logically and systematically as presented in the following sections.

2.5 Circular economy as enabler for our environment in auto arena

Different aspects of the literature, reviewed, are presented as follows:

- *Circular Economy (CE) in the auto sector*

With the global increase in vehicular population, scope of the CE application in auto sector would keep on growing day by day. Through different components of CE, described below, efforts are made to keep the material of the vehicles always in circulation. To realize circular materials flow, “3R” (reduce, reuse, recycle) process is always kept in view and CE is a kind of win-over strategy for sustainable development (Lou *et al.*, 2007). Since the last two decades or so, awareness of economics has been largely increasing within the automobile industry (Williams, 2006), while waste-management in auto sector has been drawing attention in various parts of the world (Chen *et al.*, 2019; Bi *et al.*, 2020). It has also been observed that even car-sharing kind of business strategies (like that offered by Uber etc.) are not going to retard the already accelerated pace of growth and development in the automobile sector (Wells *et al.*, 2020). This implies that CE would continue playing its role on these lines in future also.

In the context of the CE framework, while the automobile and its parts are being designed and developed, it is required to keep the customer-needs and the assembly/disassembly requirements in view so as to build these needs into the products during the manufacturing of the product and its parts. Thus, utilization of material resource consumed in automobile-related systems and their components get significantly improved and that serves the primary purpose of CE. It has been observed by Sahimaa *et al.* (2017) that CE is emerging as a potential tool for solving the global problem of scarcity of resources. This would result in achieving the kind of development termed as sustainable which implies satisfaction of present needs of humanity without damaging the interest of future generations. Similarly, Geissdoerfer *et al.* (2017) and Chhimwal *et al.* (2021) also opined that CE framework can provide a full-fledged or partial solution to such a problem. The concept of servitisation, which is service-based business modelling is also being implemented in the industry, where the OEM (original equipment manufacturer) can provide automobile on rent and replace it with a newer or remanufactured automobile when required (Joshi, 2020; Khanra *et al.*, 2021). In order to implement this concept, managers have to play a critical role from initiating to managing to supporting it by making some major changes in their organizational structures. (Hullova *et al.*, 2019). The results of the literature review on CE are presented in the table below (Table 2.1).

Table 2.1 Summary data sheet showing results of the literature survey on ‘CE’.

Issues and Their Briefs	*Authors*
Problems	
Involves designing, making, transporting, selling, recycling and recovering vehicles with more sustainable methods: best example of CE.	Buruzs *et al* (2017); Chhimwal *et al* (2021)

Issues and Their Briefs	*Authors*
Problems	
Conservation of varieties of resources, and energy-sources and also the protection of environment constitute basic framework for the modern-day philosophy of social development in different parts of the world. CE takes care of not only conservation but also circulation.	Xin (2016); Haas *et al* (2020)
Plastics industry of Europe is huge and is under the impact of CE-IT nexus.	Phung (2019)
The 'recycling' component of the CE demands the 'original' level of quality features in the remanufactured products like automobile parts, engineering machinery and machine tools.	Du *et al* (2012)
Best Practices for Collection Phase	
For gypsum/non gypsum CE practices thro' surveying statistical tests.	Jimenez-Rivero *et al* (2017)
Extension of application to car EOL auto parts.	
Key Enablers	
Design/Scale/Policy/Collection/Cost/Continuous Improvement	Buruzs *et al* (2017)
Vehicles' Parts Studied in Literature	
Wind screen wipers motors for other than EOL applications	Anca (2015)
Car doors	Soo *et al* (2016)
Impacts	
Scarcity of raw materials	Buruzs *et al* (2017)
Change in the structural materials of the vehicle	

With the introduction of CE in the technological world of automobiles, many terms such as remanufacturing, reusing, recycling and refurbishing etc. are gaining popularity. At the global level, in recent years, companies like Deloitte, McKinsey and Accenture etc. have reported extensive applications of CE in their enterprises (McKinsey, 2015; EC, 2019). It was reported recently that the aim should be to augment the recycling efforts to the extent of around seventy percent by the year 2030 through such endeavours as better use of resources and application of appropriate tools of waste management (EC, 2019). Such global companies as Alstom (for trains), BMW (for sharing of cars), CHP (for sharing apartments) and a CE leader since 2017, Steelcase (for recycling of furniture) are major contributors in the field of CE (Khalamayzer, 2018). In washing machine industry also, CE played a significant role (Bressanelli *et al.*, 2017). Summarized data on the contributions to the conceptual framework of CE is presented in the Table 2.2. The utility of such a framework span over all the industrial applications including the automobile engineering.

Table 2.2 Summarized data on the contributions to the conceptual framework of CE

Contributions to Conceptual Framework of CE	*Authors*
In 114 differently styled forms, CE has been defined in literature and these definitions represent different conceptual	Kirchherr *et al* (2017)
Stakeholders are reported to have blurred the concept of CE due to their individualistic different worlds of thinking processes.	Gladek (2017)
Such developments as 'resource efficiency' indicators, 'market value approach' and 'eco-innovation' were introduced by authors.	Maioa *et al* (2017); Blazek (2022)
The possible exchange of resources between the different elements of any supply chain can be ascertained by putting more emphasis on 'valorization of wastes'	Winans *et al* (2017)
In the businesses today, in terms of the CE applications from sustainability viewpoint, CE might be seen as a framework of 'operationalisation'.	Murray *et al* (2017)
The 'restorative and regenerative' feature of the CE targets at making the designed parts/components/products all the time valuable and	MacArthur & Waghray *et al* (2016)
CE strategies include different Rs like remanufacturing, recycling, reusing etc.; exchanging and selling the wastes; resource sharing; optimal utilization of resources and increasing the product life-span through adoption of good maintenance strategies.	Chalkias (2019); Pisitsankkhakarn *et al* (2020); Fiksel *et al* (2021); Mahapatra (2022)

A variety of research aspects pertaining to the auto-CE nexus were revealed by the literature surveyed in the present work. Some salient aspects like 'mathematical techniques applied' by previous researchers, 'Work Typography' employed by them and different 'auto parts' investigated in their respective studies were reviewed and the findings of the review are summarized in Table 2.3.

- *CE-ELV Nexus*

In general, it might be observed that statistical data pertaining to the number of 4-wheelers and 2-wheelers being discarded annually in different parts of the world do not appear to be available in the literature. In some of the developed countries efforts are being made to provide such data pertaining to discarded and/or stockpiled on national and/or regional levels (EPA, 2017). When such stockpiles of abandoned automobiles are appropriately and systematically managed it results in varieties of benefits like lesser levels of expenditure on disposal, safer environments of work, availability of the larger landfills capacity, higher earnings from scrap-yard business and finally, an enhancement of the restoring and regenerative status of the available natural sources and resources. The contents of the GHK Report (2015) provide all the details pertaining to the benefits of the 'ELV Directive'.

Table 2.3 Summarized data on the mathematical techniques, typography & auto parts/service considered in past researches.

Mathematical Techniques Applied by Researchers	*Work Typography Employed by Authors*	*Auto Parts/Service Explored by Authors*	*Year*	*Authors*
Multi-Criteria Analysis	Application	Windshield	2015	Anca
-	EOL (machine-based dismantling)	All parts/material	2015	El Halabi *et al*
Multi objective optimization	Value recovery of EOL, product;	All parts/material	2018	Jiang *et al*
AHP method	Case study in remanufacturing	Starter motors, alternators, brakes, water pumps etc.	2017	Akira
Surveying	Theoretical	Automobile sector	2018	Held *et al*
	Decision-making framework	Energy storage system	2018a	Okorie *et al*
Industrial ecology	Micro retailing of factory	-	2005	Wells & Orsato
ELV system recycling	Review	Dismantling	2015	Kryaskov *et al*
ELV management	CE-ELV	All parts/ material	2015	Despeissea *et al*
Micro factory retailing	Case study in remanufacturing industry in Japan	Auto sector	2006	Williams
SWOT analysis	Automobile reverse logistics	Auto sector	2017	Zhikang
Game theory-based model	Recycling mechanism	Power battery	2018	Tang *et al*
EOL management	CE in automobiles	Light/heavy cars	2018	Saidani *et al*

Mathematical Techniques Applied by Researchers	*Work Typography Employed by Authors*	*Auto Parts/Service Explored by Authors*	*Year*	*Authors*
Resource productivity calculation	Analytical	Automobile production	2018	Liu *et al*
Dynamic	Analytical	EOL passenger	2015	Chen *et al*
Life cycle analysis	Theoretical	Magnesium parts for reduction in car-weight	2019	Agyemang *et al*
Dynamic Material Flow Analysis (for	Analytical	-	2020	Zhang *et al*
Grey cluster model	-	All auto parts	2016	Xin
	Review	Automobile remanufacturing products	2009	Ramesh *et al*
-	-	Automobile as a service	2020	Wells *et al*
-	-	All parts of a vehicle	2007	Orsato *et al*
Fuzzy-Delphi Method	Application	-	2020	Padilla-Rivera *et al*
F-DEMATEL	Analytical	Circular Supplier Selection	2022	Munch *et al*
Game Theory	Application	Automobile panel Design	2022	Zhang *et al*

The European Directive on ELV has significantly affected ELV affairs in many parts of the world (Despeissea *et al.*, 2015; Karagoz *et al.*, 2020). The process of restoring and recovering the resources pertaining to automobiles was studied by Li *et al*. (2016) through a tool known as Life Cycle Assessment (LCA) that helps in understanding the features of environmental health. Based on the LCA, the 'Automotive Shredder Residue (ASR)' was studied by Passarini *et al.* (2012) also. So far as the ELV is concerned, some of the barriers encountered in the process of auto-parts development were reported by Wang (2018) while the variables, cost incurred and time spent appeared to be the main barriers in Malaysia (Taha *et al.*, 2010). It was revealed in a survey-based study that the process of designing and developing sustainable products was still passing through its infancy phase (Ghazilla *et al.*, 2015).

How the dismantling process is undertaken was studied in another survey-based investigation by Zhang *et al* (2017) who also observed that different tools and techniques like simulation, optimization, surveying, etc., all led to similar findings when the studies related to ELV management were compared at the global level. The understanding of ELV features got significantly improved through the contributions of Mohamad-Ali *et al* (2018) and Mamat *et al* (2016). However, the former study had a major limitation in terms of the involvement of only five stakeholders in the study. Sadhukhan (2017) observed that CE spans over three basic processes (3Rs: reduce, reuse and recycle) for waste elimination for sustainability and involves the total life cycle of all kinds of products. This implies that these components of CE are crucial for auto products as well. So far as ELV in the auto industry is concerned, Kryaskov *et al.* (2015) reported that there were only four countries (USA, China, Japan, and Korea) and one region (European Union) in the world where ELV management remained well organized. In these parts of the world, more than 50% of the worldwide automobile pool was concentrated while the developments in France were put forth in the report prepared in 2017 (ADEME, 2019). So far as India is concerned, it appears to yet take an initiative in this direction as is revealed by the following facts (Naik, 2018): Number of vehicles in India has been rising day by day right from the year 2010 when it crossed 110 million whereas it got enhanced by an additional number of vehicles amounting 103 million during the manufacturing period of the next five years (2010-2015) and this upward trend has been rising till date. In terms of the specific types of vehicles the data (in lakhs) for the passenger vehicles, commercial vehicles, three-wheelers, and two-wheelers for the year 2014 (year 2029 extrapolated) respectively are stated as 32.2(69,118.5), 6.9 (16,236.2), 94.9 (17,879.3) and 84.9 (34,103.8). Such a development in the Indian automobile industry has been exerting an ever-increasing larger pressure on the consumption of natural resources. Accordingly, road accidents are on the increase and the environment is being polluted more and more on a daily basis. As a result, vehicular obsolescence is also increasing and the scrap quantity, therefore, is getting enhanced with the passage of time. Very recently (March 2021), launched vehicle scrappage policy of the Indian government is expected to go a long way in terms of optimum utilization of resources such as fuel, metals, raw materials, etc. (Xion, 2021). Thus, the reuse or recycling process of the ELVs has got a huge potential in India indicating thereby a very promising scope of resource utilization and its conservation in the days ahead. It is estimated that about 70% of the ELVs would be getting dismantled, reused, and remarketed in India. Presently, there is no laid down policy of the Government and only informal sectors for ELV handling are available in India. Such an environment is non-scientific and needs improvement in the future.

2.6 CE under the impact of IT tools

Different dimensions of the literature, reviewed under the above-stated topic are presented as follows:

- *The Emerging Concept of CE*

Recently, in one of the exhaustive and unique publication of Kirchherr, Reike, & Hekkert, (2017), the concept of the circular economy, as appeared in the last several years' literature, spanned over the analysis of 114 definitions. They observed that 'the circular economy concept is trending both among scholars and practitioners. This is indicated by the rapid growth of peer-reviewed articles on CE: More than 100 articles were published on the topic in 2016, compared to only about 30 articles in 2014 (Geissdoerfer *et al.*, 2017). CE in its conceptual form, in the eyes of various stakeholders, can blur the concept since they frequently operate in significantly different worlds of thought (Gladek, 2017). Blurriness has been raised as a criticism against concepts such as the green economy (Loiseau *et al.*, 2016) and other similar terms (Ghisellini, Cialani, & Ulgiati, 2016). These days the circular economy (CE) concept is trending and thus much 'lip service' is given to it. Trending concepts, in general, diffuse in their meanings and it appears that same is happening to the CE concept also. Among the current CE related literature reviews, perhaps, no comprehensive and systematic analysis specifically on CE understandings was presented earlier. The comprehensive set of 114 CE definitions and systematic analysis against a coding framework, under reference, provided more transparency regarding current CE understanding. CE can be defined, within the framework of the paper, under reference, as an economic system that replaces the 'end-of-life' concept with such terms as reducing, reusing, recycling and recovering materials in production/distribution and consumption processes.

Kirchherr *et al* (2017) in their analysis of 114 definitions provided the first quantitative evidence that and how CE meant many different things to different people. Maioa *et al.* (2017) presented a new indicator for resource efficiency and the CE employing the market value approach. It might be observed that some of the authors seem to have no idea about what CE meant, whereas some authors equate CE, in its entirety with the concept of 'recycling'. On the other hand, it was revealed that the most common conceptualization of the 'how-to' of the CE is a combination of the terms like reducing, reusing and recycling. According to Ness & Xing (2017), only one third of the offered definitions, explicate a waste hierarchy. The work of Kircherr *et al.* (2017) further revealed that most authors see CE as an avenue for economic prosperity, whereas previous scholars conducting narrative reviews of the CE literature had argued that CE would be mostly concerned with environmental aims. They also confirmed that previous scholarly writings pertaining to the CE understanding mostly neglected the social considerations in their studies. Lastly, in their in-depth analysis, they also found that only one out of five definitions considered the consumer as a second enabler of CE. The significant momentum gathered by the concept holds the promise that CE may be able to reach beyond the current sustainable development efforts. The answer to the question how far is the CE really 'circular' is provided by the term 'circularity'. Saidani *et al.* (2019) explored this concept and found and classified 55 indicators of circularity. Pieroni, McAloone & Pigosso (2019) reviewed a total number of 92 approaches pertaining to the business model innovation for circular economy and sustainability and concluded that there is a need to evolve a stronger relationship between the two dimensions of 'circularity' and 'sustainability'.

- *CE: The Application Perspective*

The globally reputed consulting firms like Accenture, Deloitte, EY and McKinsey & Company all published several materials on the CE in the last two years or so (Lacy, Keeble, McNamara & Rutqvist, 2015; AS, 2016; Hestin, 2016; EC Report, 2019). Among both the scholars as well as the practitioners the CE concept is emerging to be of great interest as it is being viewed as an operationalization step for businesses to implement the much-discussed concept of sustainable development (Murray, Skene, & Haynes 2017). Many concerns, recently, have started offering circular economy services to the enterprises (Khalamayzer, 2018). The European Commission Administration (EC Report, 2019) recently recommended the recycling target to be increased to 70% by 2030 by way of focusing on packaging materials and food products optimum utilization and waste management strategies. In the real-life world, following the CE strategy in the modern-day markets of the mobile-phone sector, for example, several hand-phone manufacturers sell refurbished units of their own phones at a discounted price. Also, some of the independent companies have emerged to utilize the residual value of used phones that still function. These firms collect such phones, fix them, install fresh software, and sell them to less fortunate customers. In this manner, the secondary market for mobile phones offers an opportunity for the companies to concentrate more on the value of the material and energy they use to make their products.

In terms of the specific application perspective, many companies were reported to have sold its products as services as a part of the requirements of the CE business model. For example, in 2014, French train manufacturer Alstom evolved ‘Health Hub’, a predictive maintenance tool that monitored the health of trains, its infrastructure and signalling systems by means of advanced data analytics. Similarly, companies like BMW (car sharing on rental basis), Danish CHP (temporary apartments making Danish company), Grundfos (a pump supplier for heating, air conditioning, irrigation and water treatment company experimenting take-back strategy of CE), German company MAN Truck & Bus (an international supplier of commercial and transport vehicles to businesses) and a company that is famous as a CE leader is Steelcase which since the year 2017, has been helping other companies in reusing, donating and recycling their furniture (Khalamayzer, 2018). How the CE business models can reshape the washing machine industry is amply demonstrated by Bressanelli *et al.* (2017). In the field of waste management, Liguori & Faraco (2016) presented an enriched review of the treatment processes in biorefineries, demonstrating a good promotion of circular economy.

The recent practice-based developments in the field reflect on the business- model changes required in future in order to seize the opportunity which begins with the product development. Today, it appears that the scenario is changing fast. In many studies (e.g., Tukker, 2015) pertaining to the application in product service system, resource efficiency has been focused. Once the product developers receive specifications, they design their products accordingly. But when the products are designed keeping customers in mind, an effective method is ‘design thinking’ which is a user-centred design approach that focuses on finding the best way to meet the needs of the customers. It starts with observing customers in order to learn about their needs and about how those needs are met by the existing products. People such as product designers, engineers, marketing specialists, and many more involved in making and selling the products get the insights on the customers' needs in order to rapidly make a prototype, test and refine the underlying concepts for products and services. According to the Ellen MacArthur Foundation, 'Circular Economy is characterized as an economy that is restorative and regenerative by design which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles' (MacArthur & Waughray, 2016).

In a Circular Economy, 'companies concentrate on rethinking products and services from the bottom up to "future proof" their operations and prepare for inevitable resource constraints all the way through to the customer value proposition' (AS, 2016). In the manufacturing sector how the circular economy can be implemented by way of managing the waste and proper utilization of resources was nicely reviewed by Lieder & Rashid (2016). In many cases, the implementation of CE in manufacturing companies requires changes in their business models, which can be achieved by means of Product/Service-Systems (PSS), which presents a strategy attracting considerable attention over the past few decades or so in decoupling the economic growth from resource consumption. For the period of 2008-2017, Basu (2019) studied the problem of CE in 27 European Union Countries through a statistical software EViews 10 and enumerated the factors through which the CE model can be determined. How far the manufacturing sector scenario in India is ready for CE was illustrated through a model based on the extended theory of planned behaviour by Singh, Chakraborty, & Roy (2018). This study was conducted through a survey with application of structural equations modelling as a tool of investigation. In the context of in managerial decision-making situations on reuse, remanufacturing and recovery of materials, Li, Tao, Cheng & Zhao (2015) discussed the use of IoT. Such developments might lead to a group of smart-circular strategies: smart maintenance, smart reuse, smart remanufacturing and smart recycling (Alcayaga, Hansen, & Wiener, 2019).

- *CE and Reversed Supply Chain Logistics (RSCL) Nexus*

One of the most promising paradigms to appear in recent years is the Circular Economy, a recently emerging concept in the world of engineering and technology that represents the 'cradle to cradle' kind of model of a production system. On the other hand, the non-circular systems were based on the 'cradle to grave yard' kind of models, reflected in the forward supply chain logistics whereas the 'reversed supply chain logistics' (RSCL) are primarily representing the 'cradle to cradle' kind of models. In the context of industrial application, it may be observed that with the ever-growing pace of technological development at the global level, small and medium scale enterprises (SMEs) have been playing a critical role in both developed as well as developing economies. Rizos *et al* (2016) highlighted varieties of barriers and also the enablers pertaining to SMEs in the framework of the CE implementation. Primarily, the impact of RSCM, when viewed on the CE platform, can be traced in terms of such features as management of material flow, information flow, and revenue flow across the whole of the supply chain, but taken in the 'reversed' order i.e., from customers or end-users to the manufacturers. On the other hand, already there are evidences in literature in support of the studies pertaining to 'manufacturing flexibility' and 'strategic flexibility' (MacArthur & Waughray, 2016) that lead to the benefits of the CE concept. In light of the recently appearing global Supply Chain definitions of SCM and RSCM (Bressanelli *et al.,* 2017), the SCM framework integrates key business processes from end-users through original suppliers providing products, services, and information that add values for customers and other concerned stake holders.

On similar lines, the work on 'reversed' SCM might be undertaken. As regards the SCM and RSCM impacts on CE it may be noted that, of late, there have been many theoretical developments and formulations in the field of SCM. It has been shown that poor coordination among supply chain members has negative consequences on performance, such as inaccurate forecasts, low-capacity utilization, excessive inventory, inadequate customer service, inventory turns, inventory costs, time to market, order fulfilment response, quality, customer focus and customer satisfaction (Srai, 2016). Whatever be the characteristic involved in all the facets of "RSCM", along with the "flexibility", the 'uncertainty' is always an integral part of all varieties of business or manufacturing environments. It has been reported that not only in the context of RSCM, but in other aspects of the work environments also, the developed operational models are said to get far more superior when such models are capable of incorporating/handling the "uncertainty" dimension also. Emerging on the knowledge frontiers, such tools, as reported in literature, include stochastic and probabilistic modelling, Analytic Hierarchy Process (AHP)-based models, system dynamics tools, fuzzy set theoretic modelling, industrial simulation, micro simulation, Delphi technique and pseudo-quantitative technique etc. Researches undertaken in the recent past indicated that the use of "hypothesis testing" as a tool had increased significantly over the period particularly during the last few decades or so. Currently investigators advise a greater use of hypothesis testing and the analytic method as the Supply Chain Management and also the RSCM disciplines continue to develop (Pagoropoulos, Pigosso, & McAloone, 2017). A comprehensive review on mathematical models in the field of reverse logistics was recently undertaken by Pellicer and Valero (2018) who illustrated how the decisions in the RSCM framework are taken for better results.

- *Digitization, 'RFID' & 'IoT' Technologies' Impacts on Circular Economy*

To give a shape to it, digitization of circular economy happened, which has many perspectives especially when the areas like AI, Big Data and Internet of Things (IoT) are part and parcel of any new technological innovation. It is, however pretty vague to talk about the degree to which circular economy gets affected by these technologies at this juncture (MacArthur & Waughray, 2016). A comprehensive review (Nobre & Tavares 2017) spanning over the IT tools known as Big Data and IoT presents a good illustration of their applications in the field of CE. In a recent work, Pagoropoulos, Pigosso, & McAloone (2017) identified three architectural layers in digital technologies which have impacted the circular economy. These are: data collection, data analysis and data integration. This conclusion is based on their research pertaining to 135 case studies, in which they found that RFID (Radio Frequency IDentification) and IoT technologies have impacted 'data collection' stage, Machine learning, AI and Big Data Analytics have impacted 'data analysis' stage and RDBMS (Relational Data Base Management System) and PLM (Product Lifecycle Management) have impacted 'data integration' stage. Jabbour et al (2019) observed that CE without proper support of Big Data might not be an effective proposal and accordingly presented an integrative framework for the nexus of the CE and Big Data. However, Tseng *et al* (2018) argued that such developments are applicable to either single corporate or single supply chain. As revealed by the literature, today the term circular economy vis-à-vis digitalization is often discussed in academia in terms of decentralized manufacturing and enterprise systems.

A technology which is growing very rapidly these days is referred to as RFID technology, which uses electromagnetic fields to automatically identify and track tags attached to an object. When applied to the circular economy paradigm, RFID helps track material flows so as to enable value recovery achieved by the implementation of strategies such as Reuse, Repair and Remanufacture. RFID technology utilizes tags, sensors and barcodes, and smart phones are the most common resources used in implementing IoT (Atzori, Iera, & Morabito, 2010; Da Xu, He, & Li, 2014). The study undertaken by Stief *et al* (2018) proposed a new methodology for identification of the assembly-oriented product-family by way of involving two levels of architectural features: 'functional' and 'physical'. This might be helpful in broadening the scope of RFID systems. It has already been used to improve the efficiency of ordering systems and in the systems incorporating JIT (Just-in-Time) technology (Tsao 2017). In the context of enterprise sensing and smartness, the studies conducted by Weichhart *et al.* (2016) and Lampathaki *et al.* (2015) are worth mentioning.

Similarly, another technology named IoT is taking rounds, which uses sensors and actuators connected by networks to computing systems which can help monitor/manage health and actions of connected objects and machines (Manyika *et al.*, 2015). The role played by IoT in case of Circular Economy involves collection of information from sensors for connecting stakeholders across the value chain. Also, IoT provides a fundamental basis for evaluating the consequences of the actions taken by various stakeholders throughout the life of the physical products. The work of Salminen, Ruohomaa & Kantola (2017) reminisce the importance of IoT for circular economy, as management and analysis of data coming from various sources and is routed through data-to-service process, leading to business co-evolution of circular economy.

Though it has been observed that transition from decade of linear thinking into circular is hard (Hossfeld 2017), how can the CE challenges be met by the digital technologies was recently discussed through a case study by the work of Bressanelli *et al*. (2018). The impact of IoT on the Internet and economy will be exemplary and it is anticipated by experts of the field that about 100 billion connected IoT devices will be there and expected global economic impact will be about $11 trillion by 2025. (Rose, Eldridge & Chapin, 2015). On the other hand, Accenture has estimated for a commercial opportunity of $4.5 trillion by 2030 (Chalkias, 2019).

- *Impact of RDBMS, PLM & AI on Circular Economy*

Also, one cannot ignore the role of Relational Database Management Systems (RDBMS) and database handling systems in today's technologically advanced systems age. They are the systems where the organization of data is in formally described tables. RDBMSs have the power to integrate heterogeneous data sources, where data architecture is specified to enable the analytical requirements of the information architecture. RDBMSs and data handling systems also support the goals of circular economy, as they help in integrating the information produced by heterogeneous data collection systems such as IoT, ERP (Enterprise Resource Planning) and CRM (Customer Relationship Management) systems. In the context of adaptive calibration of fuel injection and combustion processes, Ge & Jackson (2014) argue that parallel RDBMS infrastructure can easily support adaptive calibration processes. Another supporting IT system namely Product Lifecycle Management (PLM) systems are the information management systems that can integrate data, processes, and business systems with people in an extended enterprise. PLM systems play an important role in supporting the transition to the Circular Economy, as they are of great help in integrating information across multiple life cycles and across various stakeholders in the value chain. Lieder & Rashid (2016) stressed on the importance of PLM systems at the company level, as they allow monitoring of products and parts in multiple lifecycles. Machine learning has also appeared as a practice getting widely acceptable in the industry since a quite a long time. It is based on algorithms that adapt to data without relying on the traditional rules-based programming. Also referred to as (AI), the application of machine learning algorithms such as Neural Networks which rely on mass processing of data, rather than a complicated set of rules where they identify patterns in the data and make predictions. It can be applied to the area of circular economy to support process and system optimization based on the huge amount of data. Weichhart *et al* (2016) argued that the use of AI tools and techniques for designing intelligent enterprise systems leverages the next era of computing theory and applications towards circular economy business models.

- *Big Data Analytics & Circular Economy*

Big data is a term used to describe the exponential growth and availability of data, both structured and unstructured and may be as important to business and society as the internet itself (Lewandowski, 2016; Jain *et al.*, 2017). Big Data is characterized by the four V's: Volume, Velocity, Variety and Veracity. Therefore, Big Data sets are too large and dynamic to be analyzed using traditional database techniques or commonly used software tools Meyer *et al.* (2016). On the other hand, Serban (2017) presented a detailed matter content pertaining to the impact of Big Data on company performance. How Big Data could be employed in the supply chain management was illustrated by Jain *et al.* (2017). In the automotive industry, Ge & Jackson (2014) undertook an investigation pertaining to Big Data Study strategy in terms of the cost reduction, whereas Davenport and Beans (2017) studied the impact of Big Data on company performance and found it to be a successful endeavour. Big

Data analytics when applied to circular economy is a viable approach to make use of information from various systems of record such as sensors and IoT for better decision making. In the context of the manufacturing industry, Lieder & Rashid (2016) articulated that real time data analytics can enable decision making for adaptive calibration. Srai (2016) also put the fact that data analytics can provide insights both from raw data as well as the embedded data on multiple machine/equipment/product objects. However, Lewandowski (2016) observed that it is an important consideration as to how digital technologies can use adequate IT and data management technologies to support material tracking and other specific technologies e.g., recycling. Antikainen, Uusitalo, & Reponen (2018) stressed that both networking and collaboration with stakeholders is required so as to enable circular economy business models. Finally, as initiated by Pagoropoulos, Pigosso, & McAloone (2017), as regards to life cycle stages, digital technologies for sure can help close the material loop, and therefore the primary focus is on the End of Life (EoL) and link to production. For example, RFIDs presents a system which contains valuable information on how the product was utilized by the customer. This valuable information can be used to estimate the quality level(s) of the returns and the increased transparency, and efficiency can further facilitate the integration of return flows into the forward flows. Also, according to Srai (2016), the connected manufacturing systems can enable monitoring, control, and optimization of stocks and material flow cooperation and communication over processes and networks so as to achieve the optimum localized manufacturing output to meet the city demand.

2.7 Circularity issues and blockchain technology (BT) in automotive industry.

Different dimensions of the literature, reviewed under the above-stated topic are presented as follows:

- *BT as a tool of digitization*

In 2019, the top ten technologies included BT also (Rayome, 2019) It is a ‘general-purpose technology’ alleviating waste and cost, providing information protection, and getting accelerated in use. Structurally, in BT, ‘blocks of data’ are connected through ‘cryptographic pointers’ in its ‘ledger’ It has a numerous potential providing complete transparency and trust and is equipped with many basic features. It is a powerful tool for designing future smart systems and cities generating social sustainability China reported huge BT applications including initiatives like Blockchain Network (BCN) and digital yuan. It should be backed by an appropriate regulatory mechanism for alleviation of the security risk that yields BT authentic and full of integrity thereby making supply chain management highly acceptable (Kshetri, 2018). Though it has yet not reached the desired scale of BT maturity (Wang *et al.*, 2019), BT application areas are getting widely spread globally and by 2021, the BT market would be reaching $2.3 billion (Bumblauskas *et al*., 2019). In general, digital tools' applications result in smart companies and effectuate digital sustainability. Despite theoretical support for BT, varieties of barriers and challenges in the path of BT applications have also been reported by researchers. Thus, under the umbrella of I4.0 developments, varieties of technologies including the emerging BT have evolved. Even in the most precious and universally needed sector, energy, it is reported that due to the ever-expanding demand for renewable energy resources, BT helped the 'decentralized' energy management in terms of distribution, trade, and finance-related functions (Rejeb *et al.*, 2022). However, as observed by Gigauri (2021), studies pertaining to their evaluation appear to be missing in the literature.

- *CE under the impact of BT*

A universally acceptable definition of CE is not available in the literature and it means differently to different researchers as demonstrated by Kirchherr's work of 114 definitions (Kirchherr *et al.*, 2017). CE is 'characterized as an economy that is restorative and regenerative by design which aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles' (MacArthur and Waughray, 2016). Today, CE is being treated as a strategy for targeting the 'cleaner production' and also as a tool for waste management in different parts of the industrial world. Industry 4.0 is ready to accept the impact of the sustainable industrial world of tomorrow and many globally reputed companies have employed BT in recent times (Kshetri, 2018) and at the same time, many industrial houses are in the process of applying BT for achieving so-called 'holistic' concept of sustainability. Among Fortune 100 companies, there were 82 which are employing BT (Schinckus, 2020). However, the employment of BT appears to be yet only in the conceptual and pilot stages (Zhang and Guin, 2020). Moreover, the evaluation of such newer technologies like BT is difficult due to the IT-based complexities and thus evaluation process presents another emerging topic of research for tomorrow. One major problem is high energy consumption and pollution costs due to emission problem for which Khan *et al* (2021) suggested framing new policies to tackle the problem more effectively. Cheng *et al* (2020) also studied the impact of technological innovations on the emission problem. To sum up, despite the high energy cost of BT, its application is expanding rapidly. Within the CE framework, BT enables its application faster thereby indicating the CE-BT interface to be a promising area of research in the days ahead.

- *CE-BT implications for the auto industry*

In the daily lives of a common man, the transportation systems through 'smart cars' are already on the way to be getting revolutionized in the days ahead. Recently reported, BT-based VID (Vehicle IDentity) appears to be a promising tool for the future. Once the BT building stands on the floor of IoT (Internet of Things), the built structure is bound to get equipped with a high level of smartness, decorated with billions of interconnected devices. The circular CE strategy based on recycling in the auto industry would have its short-loop constituents as varieties of sensors involving Big Data technology (Awan *et al.*, 2021 a, b) and cloud-based systems. To sum up, the literature revealed that the design process of smart cars is advancing day by day, and the induction of smartness in products results in the evolution of newer models of business and so is the case with auto manufacturing also. In addition, in the context of the digitized CE-auto framework, it was found that the study of the stakeholders' role emerged to be a 'prerequisite for circular manufacturing' (Awan, Sroufe, and Shahbaz, 2021).

- *The issues to be addressed, the knowledge gaps, and the research implications*

The above-presented literature search indicated that exploring issues like circularity and sustainability in the auto industry within the framework of CE-BT is the need of the hour. This is due to the fast-spreading use of the digitized industrial culture and rapidly growing technology of 'smartness' in the auto industry at the global as well as the national levels. As induction of BT is a recent development in manufacturing, studies pertaining to CE-BT and that too in the auto industry involving the perception of its stakeholders appear to be either few or none, especially in the Indian context. So far as BT is concerned, its 'adoption' is still in the naïve stage (Zhao *et al.*, 2019), particularly in India (Yadav *et al.*, 2020). Thus, it might be concluded that there exists a knowledge gap in terms of the availability of the data pertaining to the auto stakeholders' perception. Such data might be helpful and needed by the future policy planners for the success of digitized CE or the CE-BT-based auto manufacturing, particularly, in the Indian context. Such studies would have long-term implications for the future auto manufacturers under the upcoming and ongoing impact of the I4.0 in the industrial world. An understanding of I4.0 components that include the BT also would contribute to evolving a sustainable society and help in laying down policies on I4.0 in the future. As of now, Kamble *et al* (2021b) observed that 'there is a significant lack of knowledge' on the sustainability-I4.0 relationship. Such knowledge gaps are being addressed by the present research.

2.8 Literature review pertaining to Automotive industry and CE-I4.0 nexus through the consumers' and Manufacturers' perspectives.

Different dimensions of the literature, reviewed under the above-stated topic are presented as follows:

- *I4.0-based CE implementation*

The phrase "I4.0", ('I' standing for industry and '4.0' indicating the 4th industrial revolution), coined in Germany in 2011, includes IoT, BDA, BT, RFID, Machine Learning (ML), Robotics, AI, AM, etc. The annual investment in I4.0 by 2020 was estimated to reach around USD 900b (Chatterjee, 2021) and now is expected to reach around USD 334.18 billion by 2028 (Thomas, 2022). Another emerging development in the form of CE appears to be a good weapon for better resource utilization and environmental care by way of adopting such CE strategies as re-use, remanufacturing and recycling, etc. in the automotive industry through the identified supply chain enablers (Lahane, Prajapati & Kant, 2021). The work on the CE emerged a few decades ago whereas the I4.0 is a recently emerging area of research and the I4.0-CE nexus is reported to be presently quite attractive for investigators. Rosa *et al* (2020) even mentioned the coining of some terms like 'Circular I4.0' or 'Digital CE' in the latest available literature on CE. However, it appears that the said nexus is yet relatively less explored by researchers (Alhawari *et al.*, 2021). CE is an alternative to the classical model of 'take, make, and dispose' (Bassi & Dias, 2019). And represents its modified version in the form of a 'cradle to cradle' kind of model enabling a reduction in the use of new materials by 32% and 53% respectively by around 2035 and 2050 (Awan & Sroufe, 2022). In literature, CE is defined in many ways as cited by Kirchherr *et al* (2017) through a collection of 117 definitions of CE. Sauvé's, Bernard & Sloan (2016) defined it as the 'production and consumption of goods through closed-loop material flows that internalise environmental externalities linked to virgin resource extraction and the generation of waste (including pollution)'. On the other hand, European Environment Agency (EEA, 2014) proposed that CE "refers mainly to physical and material resource aspects of the economy – it focuses on recycling, limiting and re-using the physical inputs to the economy, and using waste as a resource leading to reduced primary resource consumption''. Thus, in the CE-I4.0 linked endeavour, the applicability of the digital tools under the umbrella of the I4.0 technologies would play a critical role in addressing the 3-pronged issues of alleviation of the scarcity of materials, minimization of environmental pollution, and finally, induction of digital culture in order to benefit the automotive industry in the days ahead. To sum up, there appears to be a profound scarcity of academic work related to the CE-Information Technology (IT) nexus at the global level (Nobre & Tavares, 2017). Such tools as IoT and BDA support a smooth transition to CE which are often related to each other strongly (Queiroz *et al.*, 2020). Also, digital tools help in achieving a boost in a sustainable CE environment, particularly in manufacturing like that in the automotive industry where huge piles of discarded vehicles and their parts are creating landfill-linked serious environmental concerns.

- *Perspectives of users on technology acceptance*

In terms of the perspectives of users in technology acceptance many studies, in the past, focused on the role of human users' perception in different spheres of engineering and technology. For example, the terms 'perceived usefulness' and

’perceived ease of use’ in the context of the ’intention to adopt technology’ was employed in the evolution of a popular model known as TAM (Chatterjee *et al.*, 2021). The ’perceived ease of use’ refers to the strength of the belief in the confidence in new technology with no effort. Thus, the success of the application of any innovative technological effort is also a function of the perception of the employees of an organization regarding their ability in performing the job associated with the upcoming I4.0 technologies (Zheng *et al.*, 2015). To sum up, the literature search indicated that among the external factors impacting the application of emerging technologies like those associated with I4.0, the intention of the technology users’ population and hence their perception and perspectives play a positive role in the writing the success story of the newly emerging technological endeavours like the I4.0 tools-based applications.

- *CE enabling factors in the automotive sector under I4.0*

In the Indian context, according to one of the latest reports of the IBEF (IBEF Report, 2022), by the year 2026, the automotive industry would become of the order of more than USD 250–280b. Under the shadow of such a huge development of the industry, both the CE as well as the I4.0 would be playing a revolutionary role in the transformation of the presently shaped industry into a modernized digital era type of industry. Also, an event like Auto Expo-The Motor Show 2020 was held in India with the conference theme being “Recycling and Circular Economy in Automotive Sector" (SIAM, 2022), in order to meet the demands of the future traffic environment. This event served as a precursor to the future scope of the CE execution in the Indian automotive industry. In the context of the CE-I4.0 nexus, the technologies like RFID and IoT are employed for collecting data whereas the analysis of data might be undertaken through technologies like BDA. On the other hand, product life cycle management and RDMS help in the integration of data. In light of the recent literature reviewed by researchers (Tang, Chau & Fatima, 2022; Ding & Jiang, 2017; Elelzalde, 2021; Pagoropoulos, Pigosso, & McAloone, 2017), and the experts’ opinions (detailed elsewhere), enabling factors were identified as shown in Table 1. The standard deviation values for these investigated variables were found to range from 0.496 to 0.748 for the manufacturers and 0.6 to 1.05 for the end-users, with the exception of T12 to T16, which were all for manufacturers.

- *Digitised green era of manufacturing*

Digital tools help in achieving a boost in a sustainable CE environment, particularly in manufacturing like that in the auto industry where not only huge piles of discarded vehicles and their parts but also the varieties of ‘returns’ are creating a lot of landfill-linked serious environmental concerns. All such happenings retard the progress in the direly needed culture of green technological environment for tomorrow. On one hand, I4.0 technology applications are generating a digitised world of manufacturing and, on the other hand, the ongoing scarcity of resources under the excessive demands of manufactured products and the resulting damages to the environment are giving birth to new kinds of research parameters in the concerned field. Under the banner of green culture, even green economy and green banks kind of concepts have emerged in recent literature e.g., Hang (2022). It was also found that in the context of CE and sustainable production, the green financing system plays a critical role, whereas CE gets significantly affected positively by sustainable manufacturing (Jinru *et al.*, 2022). Similarly, Khan *et al (*2022) studied the relationship between economy and environment and highlighted some critical barriers pertaining to the adoption of green financial culture.

2.9 Literature review pertaining to CE-driven Returns and Recovery Management in the Indian Automotive Industry

Different dimensions of the literature, reviewed under the above-stated topic are presented as follows:

- *CE Developments and the auto industry*

CE appears to be a topic that is frequently discussed in literature (e.g., Thomas *et al*., 2022; Nobre *et al*., 2017; Pagoropoulos, Pigosso, & McAloone, 2017), and Kirchherr *et al*. (2017)'s collection of 114 definitions of the CE provides a thorough account of how it is defined by scholars. A circular economy, according to the EPA, "reduces the use of materials, redesigns materials, products, and services to be less resource intensive, and recaptures "waste" as a resource to manufacture new materials and products." (EPA, 2022). The application of CE gets exceedingly beneficial in the automotive industry when seen from the viewpoint of the waste from landfills, resulting in significant environmental degradation problems. In this context, what might be the critical factors was well illustrated by Akinade *et al*. (2017). The study of Berzi *et al*. (2016) related to the evaluation of hybrid scooters in terms of their EOL (end-of-life) performance. Olugu and Wong (2012) developed an expert system specifically for the automobile sector. Pauliuk (2018) established the CE standards, whereas Suarez-Eiroa *et al*. (2019) suggested a method for connecting theoretical research with real-world applications throughout the implementation of CE. By adhering to the CE framework, Nascimento *et al*. (2021) developed a model that helps reintroduce automotive waste into the manufacturing recycling process. According to Wang *et al*. (2023), the remanufacturing component of CE was found to yield more benefits in the Chinese automotive industry when compared with the recycling one.

All such actions within the CE framework result in the ‘extraction’ of the value of the materials involved that would have otherwise gone to add to the waste management problems and also the land filling form of the environmental problem, thereby injuring societal health too (Wells and Seitz 2005). Tang, Chau & Fatima (2022) clearly defined the phrase environmental sustainability, which mirrors the UN's seventeen SDGs, of which Goals 9 and 12 apply to sustainable manufacturing (UN, 2021), which are pretty relevant in the case of the automotive sector as well (Drohomeretski *et al*., 2015). To summarise, with the fast-moving economy of the world and enhanced rate of urbanisation at the global level, the world population is witnessing more and more dependence on technological developments. These contribute to the fast depletion of valuable resources and also to degradation of environmental health, thereby necessitating CE-based technological endeavours in all industrial sectors, including the automotive industry. While the CE framework is being extensively researched, no comprehensive framework for the CE application in the vehicle sector is yet available (Esteva *et al*., 2020).

- *The Return and Recovery Management (RRM) systems*

Since more than two decades or so, the topic of ‘return and recovery’ of the products has been an area of research and continues to be so today under the titles of CLSP (Closed Loop Supply Chain), RSC (Reversed Supply Chain), and CE in the modern days of innovative technologies. While discussing e-commerce returns, Nanayakkara *et al*. (2022) referred to the historical Rogers’ classification of returns of goods in terms of consumer type returns, marketing type returns, product types, recalls, and environmental type returns. They also observed that consumers’ or end-users’-related returns primarily occur due to defects in goods or the user’s dissatisfaction, and such returns are of the largest type in size. The present trends indicate that the high cost of handling the returned goods results in the evolution of an easy policy, referred to as a lenient returns policy’ (Janakiraman and Ordóñez, 2011). Thierry *et al*. (1995) termed repair, refurbishing, remanufacturing, cannibalization, and recycling as five types of recovery processes. In contrast, Fleischmann *et al*. (2000) proposed collection, inspection or separation, reprocessing, disposal, and redistribution as five different phases of recovery. Also, different drivers of the returns were named in the literature (e.g., Fleischmann *et al*., 2000). On the one hand, the term ‘drivers’ indicated the reasons for returns, and, on the other, types’ denoted the kind of goods/products/components that were returned by their end-users. Based on the reasons for returns, the returns are categorized into consumer type, marketing type, asset type, product recall type, and environmental type. Also, Stock, Speh & Shear. (2006) classified them into controllable returns that can be minimised, if not eliminated, and uncontrollable returns. In another classification, manufacturing type, distribution type, and customer type of returns appeared (De Brito and Dekker, 2004). Another approach for grouping returns is the approach taken by Stock, Speh & Shear (2006), who grouped the returns in controllable and uncontrollable forms only. Bonev (2012) mentioned some reasons for the returned products in descriptive forms. In the context of those parts or components that might be obtained as a result of the returns or recovery process, how their performance is evaluated was discussed by Wibowo and Grandhi (2017). In many countries, customers are given a refund for the items returned by the users at various ‘return-centres’ and this results in an incentive for the avoidance of midnight dumping’ (Walls, 2011). Such schemes, for example, were implemented in the USA, in Michigan State (Walls, 2011), and in Finland, where the beverage industry provided some money in return. (YLE News, 2019). Interestingly, India, as a nation, has also awakened to the problem of environmental degradation due to automotive industry waste, and appropriate action based on scientific methods regarding recovery and returns is emerging as the need of the hour.

- *Role of the stakeholders' perspectives*

Manufacturers and consumers, or end-users, may be the most essential stakeholders in the supply chain in terms of return and recovery, and their opinions are vital to the overall functioning and success of the supply chain. By extending the manufacturers' responsibility over the whole life cycle of the product, it becomes beneficial to them as well as other stakeholders (Peng *et al*., 2023). In the context of the perspectives of the technology users, Chatterji *et al*. (2021) discussed the 'technology acceptance model (TAM), in which the terms 'perceived ease of use' and intention to adapt technology, etc. were presented. The return and recovery systems of the automotive industry involve two distinct phases of activities: one at the manufacturer's level and another at the end-users' level. The former would be equipped with a will to get back the returned items, and the latter should have a will to return the items to their producer after some financial compensation. To summarise, on the one hand, the manufacturers would undergo a revolution due to the effects of developments in the digital era, and on the other hand, it would be necessary to spread knowledge about digital applications like the Internet of Things (IoT), RFID (Radio Frequency IDentification), etc. among the end-users of the auto industry in order to positively influence their perspectives on CE-based RRM systems. By introducing the spirit and desire to return the car parts and systems to the collection centres and recycling stations, such modifications would eventually increase the efficiency of recovering automotive components.

2.10 Research gaps

The detailed literature search on the themes pertaining to the present research presented as above revealed different aspects of the research gaps in the research works of the previous researchers. These gaps are presented in a summarized form in the following table (Table 2.4)

The present research, perhaps, for the first time, contributes to the knowledge of the auto industry stakeholders on the I4.0 and CE nexus. Besides these research gaps, the present research was also planned to explore, from the auto stakeholders' viewpoints, the potential of the application of blockchain technology (BT), the I4.0, and the returns and recovery management (RRM) in the auto industry with special reference to the issue of 'sustainability and circularity' in the Indian context.

Table 2.4. Research Gaps presented in a summarized form.

SNo	*Research Gaps*	*References*
1.	Within emerging concepts such as Industry 4.0 (I4.0) and the Internet of Things (IoT), understanding decision-making and stakeholders' interaction is important in optimizing manufacturing and post-manufacturing processes.	Jimenez-Rivero & Garcia-Navarro (2017)
2.	Recycling a large number of the spent power batteries of electric vehicles in China will become a substantial challenge in the near future. No specific mechanisms and policies for recycling spent power batteries yet framed.	Tang *et al* (2018)
3.	They applied automotive market simulator (AMaSi) to analyze the leverage of manufacturers to support the market diffusion of electric vehicles. Manufacturers should proactively strive to shape the electric vehicle market.	Kieckhafer *et al*, 2016.
4.	Developing Product service systems (PSSs) which should focus on behavioral changes and system innovation in the automobile industry.	Williams (2006)
5.	Strengthening green awareness is important to manage disposal of end-of-life automotive from an environmental perspective. Improving consumers' awareness of protection environmental, and national awareness of the reverse logistics' significance for automotive, sparkplug the green concept about low-carbon, environment friendly and energy-saving.	Williams (2006)
6.	Scrap automotive piled up in the community will have a series of issues like environmental pollution, traffic safety issues, energy issues etc.	Zhaoanjian & Yang (2014)
7.	With the high production rate of automotive, a certain number of automotives must be disposed of. This number might be same or a slightly lower as the production rate.	Williams (2006)
8.	Li-ion batteries' demand for automobile expected to increase in next 15-20 years. Recycling cathode materials from end-of-life batteries provides a sustainable source of materials, and offers an economic alternative for some of the high value elements such as cobalt and nickel.	Steward *et al* (2019)
9.	More attention should be on scrap car recycling management.	

SNo	*Research Gaps*	*References*
10.	Future research issues should include reverse logistics (RL) implementation, knowledge of existing problems of RL & the methods in the Automotive Industry and to improve management of current end-of-life automotive based on environmental view.	
11.	With immense competition in the automotive consumer market, the car reverse logistics must be given due attention as well.	
12.	It was found by that 'despite a massive volume of scientific work in these areas (e.g., separate queries in Scopus using Industry 4.0 and Circular Economy as key words yield 4060 and 2452 published documents, respectively), there is plenty of growth potential for ground breaking research in their nexus.	Tseng *et al* (2018)
13.	Need to develop models based on minimized level of linear thinking in CE since every element impacts the other.	Bruzs & Tom (2017)
14	Chances of employment of digital platforms in getting the CE activated and the potential solutions which could be obtained digitally to overcome the barriers are discussed. Based on it, issues are identified for economically and ecologically befitting digital platforms.	Berg (2019)
15	In case of 'sustainable traceability', blockchain technology can bring a revolution in the field. In this context, five major challenges viz., technical, interoperability and standardization, social and institutional and system performance required to be addressed by future researchers.	Huanhuan *et al* (2020)
16	Presently it is observed that 'our world economy is only 9.1% circular, leaving a massive "Circularity Gap".	Blanca *et al* (2019)

In the context of digitization era, specially the blockchain technology related developments and in light of the absence of the industrial-digitization evaluation guidelines, recent developments in the field indicate an urgent need for evaluation of digital technology in the implementation of 'circularity' in industrial houses, especially, when it is noted that the related areas 'are yet severely under researched' (Alhawari *et al.*, 2021). Particularly, in the auto industry, in this context, there appears to be a gap in research. Also, an understanding of the interest of stakeholders like suppliers and customers, in the context of CE initiatives, is needed and presently there is a lack of research on the topic (Awan, Sroufe, and Shahbaz, 2021).

2.11 Concluding words

The novelty of this research becomes more apparent when it is noted that the need of the time is to explore the relationship between CE initiatives and the stakeholders' perceptions and expectations (Govindan & Hasanagic, 2018). Such studies are also needed because the auto industry in India and elsewhere too plays a critical role in industrial development and employment generation. The intent of this work lies in the variety of perceptions obtained from different kinds of auto stakeholders considered, thereby enriching the literature on the study of the CE-BT, CE-I4.0 and RRM in the auto industry. In addition, the study pertains to the Indian auto industry with which is associated a large crowd of car users. Therefore, present research would go a long way in policy planning in the stated fields, particularly, in developing nations of the world.

In the next Chapter (Chapter III), the research methodology applied in various investigations pertaining to the present research are described as follows.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Introduction

The comprehensive state-of the-art based literature review was undertaken as discussed in the previous chapter (Chapter II). On the basis of the reviewed matter content research gaps were identified. Accordingly, the research issues pertaining to the current literature on the automotive industry vis-a-vis CE-IT tools emerged. In light of the emerging issues of research, present set of five objectives were laid down for the present research. These objectives are put forth in the next section (Section 3.2) as follows:

3.2 Research objectives

As stated earlier in Chapter I, the laid down research objectives are as given below:

- To study and analyze the Indian automobile manufacturing industry from a circular economy perspective.
- To study and analyze the role of IT tools in the automobile manufacturing industry.
- To develop the models for adopting and implementing circularity concepts in the industry by way of exploration pertaining to CE-BT nexus in the automotive industry.
- To explore the circularity issues through a case study by way of by way of exploration pertaining to CE-Industry 4.0 nexus in the automotive industry.
- To develop a framework for the performance evaluation of the industry by way of exploration pertaining to Return and Recovery Management (RRM) study in the automotive industry.

Corresponding to the five respective research objectives stated as above, the five respective research problems, based on the explored current literature, as presented in the previous chapter (Chapter II), were formulated for the present research as follows

- To study through a content-based systematic literature review how the circular economy (CE) and its respective components' applications impacted the automotive industry and what is the future scope of research in the concerned fields.

- To study through a content-based systematic literature review how the CE and Reversed Supply Chain Logistics (RSCL) nexus changed under the impact of the IT tools and their applications'
- To explore from the automotive industry stakeholders' perception viewpoints, the potential of the application of the blockchain technology (BT) with special reference to the issues of 'sustainability and circularity' in the Indian context.
- To explore the impacts of the circular economy-Industry 4.0 nexus on the Indian automotive industry from the perspectives of stakeholders of the automotive industry.
- To study the automotive industry stakeholders' perspectives on the return and recovery of vehicles and their parts in the Indian automotive industry within the framework of CE-based Return and Recovery Management (RRM).

In order to conduct the above-stated research investigations, the research methodologies employed in the respective researches are presented as follows.

3.3 Research methodology

Different facets of the research methodology employed for the present research are briefed as follows:

3.3.1 General research approach and research design

In the present research work, in all, five studies were undertaken. The first two studies were review-based explorations for which the well laid down methods of literature review were identified and applied in order to develop a better understanding CE and CE-I4.0 nexus application-status for designing and developing a more sustainable automotive industry in future. The remaining three investigations were all based on respective case studies. These investigations involved industry-based data collection so that the results obtained might assist the policy planners of the Indian automotive industry in terms of the CE and I4.0 based technological inductions for a healthier social environment and more efficient resource utilisation.

In general, a research design primarily answers the research questions associated with problem being explored. Research approach and the research objectives which are usually a part of the research design are already presented as above. Other components of the research design span over statements pertaining to primary/secondary research, the sampling methods (or subject selection criteria), and, finally, the data collection and data analysis methods (McCombes, 2023). Accordingly, the research design pertaining to the present study is put forth as follows:

To meet the already stated research objectives, present study employed the qualitative approach for the literature review-based studies and quantitative approach for the modelling-based studies. The sample size employed in of the first two studies respectively spanned over 163 and 63 number of reviewed research units (research papers). The modelling-based three investigations involved the sample-population of the manufacturers and the end-users of the automotive industry spread over Dehi-NCR part of India. The data collection procedure for the literature-based first two studies primarily spanned over the internet-based resources and the international publications. For the remaining three studies, the respective questionnaires were designed and developed, administered among the potential respondents. The sample sizes in the BT-related were 45 automotive manufacturers, in the I 4.0 related research were 98 manufacturers and 294 end-users of the products of the automotive industry. In the last study, the sample sizes were 63 automotive manufacturers and 294 end-users of the products of the automotive industry. The responses were obtained on the Likert scale carrying different response-numerals from 1 to 5 or 7 with their respective meanings of the rating-specifications which were provided to the concerned respondents.

3.3.2 Research methodology for literature review-based studies

There were two literature-reviews based explorations in the present research. The first one was designed to study and analyze the Indian automobile manufacturing industry from the circular economy (CE) perspective, whereas the second study aimed at studying and analysing the Indian automobile manufacturing industry from the circular economy-I4.0 nexus perspective. It might be observed that a good research methodology for conducting a systematic literature review based on 'content analysis' was proposed by Seuring & Gold (2012). They indicated some milestones in terms of material collection, descriptive analysis, pattern of analytic categories and finally, material evaluation and research quality. The same approach was employed in the present research also. For the two studies the same research methodology i.e., the 'content analysis' was employed. Thus, the results obtained would be yielding unbiased or less biased findings on CE and RSCL nexus under the impact of the recently evolved tools of IT.

(a)Research methodology employed in CE-literature related research

The present paper primarily based on structured literature search employed the content analysis kind of research methodology, which, according to Seuring & Gold (2012) is a systematic methodology and yields a process structure comprising of different components as described and illustrated in what follows:

- *Material/Data Collection Component*

The present effort of data collection is based on the references of the published researches (each reference being considered as a 'unit of analysis' for this investigation) undertaken by the previous investigators, over a span of the last decade or so, majority of them being post 2014 publications, available on varieties of the electronic and print media. The resource materials, scattered over various databases and libraries, were sampled from such data sources as Science Direct, Scopus, Web of Science, and Taylor & Francis, through the selected relevant keywords (shown in Table 1) pertaining to the involved fields of investigation. The search results corresponding to the searched keywords were obtained from different sources as indicated in the Table 1. Searching of these keywords remained confined to the documents' keywords, their abstracts and their titles. Out of these searched matter contents, those to be included in the present study were selected. The selection criteria were to opt for only English language-based literature and all such journals' papers and web-based papers which were peer reviewed. Among the researchers, such matter contents are well accepted and therefore, each one of them in the present work represents an appropriate 'unit of analysis'. Such a model of 'content analysis' was proposed and employed by earlier researchers also (Seuring & Gold, 2012; Rizvi *et al.*, 2021).

Table 3.1 Literature Search in terms of number of papers/documents found in different data-sources

Key words	*Data Source: Science Direct*		*Data Source: Scopus*		*Data Source: Web of Science*		*Data Source: Taylor & Francis*	
	Rev-iew-type	*Res-earch-type*	*Rev-iew-type*	*Res-earch-type*	*Rev-iew-type*	*Res-earch-type*	*Rev-iew-type*	*Res-earch-type*
'CE and 'Automo-bile' together	332	1,527	10	134	6	31	104	5643
'EoL Vehicles'	15,896	114,610	297	3579	161	927	2468	96082
'Material Circulat-ion and Autom-obile'	569	2,603	8	45	2	4	62	3202
'Material Circula-tion and Two Wheelers'	772	3,667	2	2	1	-	113	5925

The data/material of the 'content analysis' spanned over specific sources of data (e.g., journals etc.), their publication times (the year), thematic areas of the reviewed literature (e.g. CE and its components, CE-IT nexus in automobile engineering etc.), their typographic features and the study tools utilized in the reviewed literature. All of these along with their respective categories are explained in the subsequent sections.

- *Descriptive Analysis Component*

This component of the content analysis provides a scale to estimate basic features of the material or data collected for the study as referred to in the previous Section (Section1.2.1). All the descriptive features of the literature-search spread over the selected units are represented by this component. Literature suggested that minimum requirement for the descriptive analysis phase is to display at least these two features: distributions over time horizon and distribution over journals/reports etc. (Seuring & Gold, 2012). Accordingly, the analysis was undertaken in the present work. Following this strategy of exploration led to yield unbiased or less biased results pertaining to the CE framework application to the automobile industry.

- *Categorization Component*

The identification of different categories of the matter content involves specification of its structural dimensions based on which categories are formed so as to apply these categories for the analysis/synthesis of the matter content included in the study. In light of the pertinent keywords closely connected to the RP (Research Problem) mentioned earlier (Section 1), the relevant categories were structured and utilized in the present work as given below:

(A) Sources of the reviewed literature are categorized as Type-1: Research Journals' Papers; Type-2: Conference/Seminar/Webinar Papers; Type-3: Other Research-based materials (e.g., company/industry documents etc.).

(B)Publication Time (Year) of the reviewed literature is categorized as Type-1: 2022's Publications; Type-2: 2021's; Type-3: 2020's; Type-4: 2019's; Type-5: 2018's; Type-6: 2017's; Type-7: 2016's; Type-8: 2015's and earlier publications.

(C)Typography of the reviewed literature are categorized as Type-1: Review-oriented; Type-2: Research-oriented; Type-3: Application-oriented.

(D)Thematic areas of the reviewed literature are categorized as Type-1: CE and its Components; Type-2: CE-IT nexus in automobile engineering; Type-3: Automobile-CE Nexus; Type-4: ELV Concept and CE.

(E) Study Tools utilized in the reviewed literature are categorized as Type-1: Analytical Tools; Type-2: Non- Analytical (Qualitative) Tools; Type-3: Other Tools (e.g., software-based tools etc.).

- *Material evaluation component*

In the context of the 'content analysis' the component, 'material evaluation' depends on how clearly the categories have been formed and the coding scheme has been structured. In order to ensure this kind of clarity, it is required that the investigators should hold a thorough discussion among themselves. An exercise of this nature would result in the internal validity of the findings. In principle, once the team of researchers (i.e., the authors) gets involved in the process, the samples' reliability and validity also gets augmented in terms of the employment of the measures for the inter-coder reliability available in literature.

b) Research methodology employed CE-IT tools related research

A good research methodology for conducting a systematic literature review based on content analysis was proposed by Seuring & Gold (2012). They indicated some milestones in terms of material collection, descriptive analysis, pattern of analytic categories and finally, material evaluation and research quality. The same approach was employed for the present study as well resulting in unbiased or less biased findings on CE and RSCL nexus under the impact of the recently evolved tools of IT, as given below:

- *Material Collection Phase*

The unit of analysis for the review was taken as one research publication or reference out of the selected research works (material or data) to be reviewed. Data or for the analysis were collected through print and electronic media available on such platforms as Scopus, Google Scholar, Web of Science etc. by way of the relevant keywords associated with the fields of investigation as per guidelines of literature review, proposed by Seuring & Gold (2012) and Pagoropoulos, Pigosso, & McAloone (2017). In all, a total number of 128 papers were collected on the associated and linked topics, their abstracts were reviewed and finally the most related works, numbering 63 were selected and reviewed critically. Their selection criteria revolved around primarily, first, on the content basis of the areas associated with the CE-RSCL-DIGITIZATION linkages, their sources, the work typography, employed analytical tools, and, latency of publications, each one of which was as described in the next Section.

- *Descriptive Analysis and Pattern of Analytic Categorization*

Based on the relevant keywords associated with the RQ (research question) as stated earlier, the data were analyzed by way of undertaking the analysing of the research works included in the present study. As illustrated in terms of the phrase employed by Pagoropoulos, Pigosso, & McAloone (2017), the 'coding scheme' in the present study was as follows:

(a) Reviewed Data Work source (Journals)

Series-1 based on Journals: Here 'journals refer to 'a periodical publication in which scholarship relating to a particular academic discipline is published'. (Wikipedia; en.wikipedia.org/wiki/Research journal),
Series-2 based on Company/Industry Reports and Documents
Series-3 based on Conference/ Workshop Proceedings

(b) Latency of work (Year of publication)

Series-1, Series-2, Series-3, Series-4, Series-5, Series-6, Series-7 and Series-8 represent the publications corresponding to the years 2019, 2018, 2017, 2016, 2015, 2014, 2012 and 2010 respectively.

(c) Data Fields/areas (Topic/Topics of the paper)

Series-1: Circular Economy (CE)-based [The underlying idea behind CE is to create products which are durable, easy to reuse, remanufacture or recycle and, of course, profitable].
Series-2: Reversed Supply Chain Logistics (RSCL)-based [The contents of the unit involve logistics that is reversed, rather than forward. The entire travelling components like planning, implementing and controlling processes of logistics involving flow of raw materials, in-process inventory items, finished products and associated information flow move from the end-users to the point of origin in order to recapture the value or to get it disposed properly]
Series-3: Digital Technology (DT)-based [As observed by Antikainen *et al* (2018), digitization is a good enabler of CE In the present work, DT refers to such developments in the field of IT (Information Technology) tools as RFID, IoT, Big Data etc which have emerged recently and are being employed in the field of CE]
Series-4: Digital Technology (DT)-CE Nexus-based [Contents of the unit relate to the interactive relationship between DT and CE areas of knowledge].
Series-5: Digital Technology (DT)-RSCL Nexus-based [Contents of the unit relate to the interactive relationship between DT and RSCL areas of knowledge].

(d) Work typography

Series-1: Research based [Basically, the contents of the unit are theoretical in nature].
Series-2: Application based [The contents of the unit are based on industry-related or trade related work]

Series-3: Review based [The contents of the unit represent a critical evaluation of the previously undertaken investigations published in research journals and other forms of publications].

(e) Employed Tools

Series1: Quantitative Tools based [Pertains to the quantitative research representing the systematic investigation of the subject-matter by gathering data that can be quantified through statistical, mathematical or computational techniques with the objective of developing and employing mathematical models, theories, and hypotheses pertaining to the phenomena being studied. To be specific, examples of the quantitative tools include AHP (Analytical Hierarchy Process), ANOVA (Analysis of Variance), BWM (Best Worst Method) etc].
Series-2: Qualitative Tools based [The contents represent a research work undertaken on scientific lines through non numeric data and spread over concepts, definitions and symbols etc.].
Series-3: Digital Technology Tools based [The contents of the unit involve the digital technology (DT) tools, as specified earlier under part (c); Series-3].

3.3.3 Research methodology for modelling-based investigations

As stated earlier, there were three explorations undertaken in the present research. The first one of the three was planned to study and analyze the role of blockchain technology (BT) in the Indian automobile manufacturing industry through one of the recently evolved research methodologies, under the umbrella of the multicriteria decision making method (MCDM). This technique is called 'Best Worst Method (BWM)' In the exploration, under reference, the same methodology i. e. BWM, was employed. The next study was designed to explore the circularity issues through a case study by way of exploration pertaining to CE-Industry 4.0 nexus in the Indian automotive industry. Finally, the last study was undertaken in the present research to develop a framework for the performance evaluation of the industry by way of exploration pertaining to Return and Recovery Management (RRM) study in the Indian automotive industry. For both the studies (Study-4 and Study-5), the analytical tools employed for data analysis were based on the well documented research methodology called Factor analysis (FA) and its other offshoots known as Exploratory Factor Analysis (EFA) and Principal Component Analysis (PCA). These tools helped in identifying the key enabling factors to answer the related research questions (RQ). Also, a Confirmatory Factor Analysis (CFA) was employed to fit the model over the data obtained from EFA, and, finally, in the last study, cluster analysis was also employed as a tool for an in-depth investigation. This study aimed to develop the models for the adoption and implementation of circularity concepts through returns and recovery system based on the perception of stakeholders in the automotive industry.

(a)Research methodology employed in BT-related research.

Different facets of the research methodology employed for the present investigation are discussed as follows:

- *Proposed operational CE-BT model for the auto industry*

CE closes the open-loop by way of induction of another connecting box called 'recycling'. In terms of BT, 'tasks' are referred to as 'transactions' while their 'managers' are named as 'agents' and the same would be employed in the proposed model also. For being more efficient and reliable model, the blockchain framework-based CE model is proposed. The BT networks would involve 'decentralized' constituents under different 'agents' who need not be 'trustworthy'. The characteristics of 'reliability' and 'security' are inducted through the 'cryptographic' nature of the BT system. All the transactions are recorded on multilayered ledgers by different users of the CE-BT system. The induction of blockchain in the new model of the auto supply chain would enable all the users of the auto network situated in their respective decentralized locations to record and read their respective transactions in their respective ledgers. All the activities of the CE-BT users are coordinated by the 'blockchain' at the center whereas its layers constitute the satellites surrounding the blockchain as is shown in Fig 3.1.

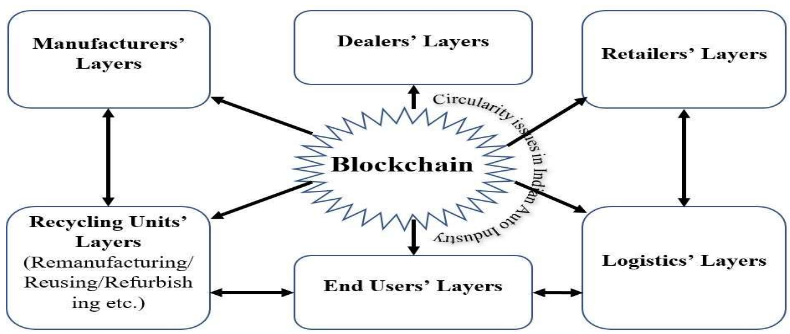


Fig 3.1 Activities of the CE-BT interface

- *Evaluation of Indian auto stakeholders' perception of CE-BT use*

The following sections explain the conceptual framework of the present study along with the research and data methodology employed to test the hypotheses structured as given below:

- *Conceptual framework and hypotheses development*

The procedure of the 'Evaluation of the Perception of Auto Stakeholders' (EPASH) on CE-BT is presented conceptually in the framework as an MCDM problem as shown in Table 3.2 in which three primary criteria to measure EPASH in CE-BT study were taken as BT potential (BTP), BT barriers (BTB) and BT application (BTA) with their 5 respective sub-criteria as BTP1 to BTP5; BTB1to BTB5, and BTA1 to BTA5. To test the CE-BT impacts following hypotheses were structured:

Table 3.2 Measures of EPASH on CE-BT nexus impacts as adopted from different sources

Main Criteria/ Sub-Criteria	*Sources*	*Main Criteria / Sub-Criteria*	*Sources*
BT Potential (BTP)/ BTP1 to BTP5	Antikainen, Uusitalo, & Kivikytö-Reponen, 2018; Corsini, Gusmerotti, & Frey, 2023; Rejeb, Rejeb, & Keogh, 2022; Saberi *et al.,* 2019; Upadhyay *et al.,* 2021	*BT Applications (BTA)/* BTA1 to BTA5	Abid *et al.,* (2024); Corsini, Gusmerotti, & Frey, 2023; Gerger, 2021; Kouhizadeh, Saberi, & Sarkis (2021); Rejeb, Rejeb, & Keogh (2022); Upadhyay *et al.,* 2021
BT Barriers (BTB/ BTB1 to BTB5	Abid *et al.,* (2024); Antikainen, Uusitalo, & Kivikytö-Reponen, 2018; Dalenogare *et al*., 2018; Lobo & de Oliveira, 2021; Saberi, Kouhizadeh, & Sarkis, 2019; Rejeb *et al.,* 2022;		

H1: All the considered factors related to 'BTP', 'BTB', and 'BTA', within the CE framework have the same influence on the stakeholders' perceived decision-making in the Indian auto industry, and
H2: All the considered three (manufacturers, dealers, and end-users) Indian auto stakeholders' perceptions about CE-BT impacts weigh equally in terms of the investigated factors.

It is worth noting that data obtained from varieties of the stakeholders lead to sound analysis and good results (Zhang, 2019) and accordingly the stated hypotheses were tested as follows:

- *Research and data methodology*

The data sets utilized are the responses of the three auto stakeholders in terms of their perception of CE-BT impacts on the auto industry (expressed on a Likert scale of 1 to 5} obtained through the questionnaire (Appendix I). The data sets include the specific queries pertaining to CE-BT impacts and the response entry cells (to be filled in by the respondents). The variables are the decision criteria (above stated 3 in number:) and their sub-criteria (above stated 5 in number). Thus, there are 3 x 5= 15 variables considered. The indicators which form the base of the analysis include the scores obtained through BWM involving weighting procedures.

- *Research instrument employed and data sets*

A research instrument based on the literature search was needed to be designed to cater to the tested hypothesis needs. To get the measures of the EPASH on the CE-BT nexus, two sets of data were needed:
(a) Optimal WEIGHT for the criteria, (w_1*, w_2*,…,w_n*) and
(b) EPASH SCORES (on the various criteria).

To determine weights, five IT experts' opinions were considered, while, to determine the scores, the data were collected through the research instrument (Appendix-I) employed for surveying the auto stakeholders, spread over different auto users, auto dealers and auto manufacturers, numbering around 30, 5 and 10 respectively mostly from north India. Responses were obtained through the Likert-like scale of scores varying from 1 (least important) to 5 (most important) numerals.

- *Respondents' profiles*

In surveying, the auto companies targeted were those having experience in the CE and BT. Respondents, participating voluntarily desired their data to be kept confidential. Their demographic profiles are presented in Appendix A1.

- *Research methodology selected for Hypothesis Testing*

Out of varieties of MCDM tools, the present study selected a newly developed technique called BWM. As compared to other techniques, BWM is simpler, needs lesser data and yields more consistent and structured comparisons (therefore, more reliable results). Salimi and Rezaei (2018). cited varieties of practical situations (e.g., risk assessment, supplier segmentation, and selection, supply chain management, water management, innovation management, etc.) where BWM was employed as a tool by different researchers in the past. In a recent study related to the barriers to BT adoption in CE, Rejeb *et al* (2022) also employed the BWM as a technique of data analysis. In this study, the EPASH problem was expressed as an MCDM problem as shown in Table 3.1. The objective is to select B*, the best (e.g., most valuable, most important) alternative out of the three perceptions of the considered three stakeholders of the auto industry. The BWM uses pair-wise comparison to find the weights (w_j*) of the criteria and shows how much the decision-maker prefers criterion i over criterion j. The procedural steps followed were the same as Rezaei (2015), briefed as follows:

(1) A set of decision criteria is determined.

(2) The B(Best) and the W(Worst) criterion from experts' viewpoints are found

(3) On the Likert scale (1 to 5), the preference of B over all others yields BO (best to others) vector.

(4) Similarly, OW (others to worst) vector is determined.

(5) Determine the optimal weight (w1*,……,wn*).

Thus, a Linear Programming problem, as briefed by Rejeb *et al.* (2022), is obtained and its solution yields the values of the optimal weights and the objective function providing the value of the consistency ratio (CR). The lower CR values imply more consistent and more reliable results. For MCDM problems with more than one level, we should identify the weights for different levels following the BWM steps, after which we can multiply the weights of different levels to determine the global weights.

(b) Research methodology employed in CE-I4.0 related research

Different aspects of the research methodology employed for the present investigation are presented as follows:

- *Conceptual model and hypotheses development*

AI, ML, and BDA roles in manufacturing were highlighted by many researchers recently while IoT helped in making vehicles smart. The concepts of smart factories and smart robots in a German automotive firm were also reported (Ivanov *et al.*, 2021). 'Digital twin' and 'Digital thread' are also trending in the industry, both relying on IoT sensors. However, such studies in the manufacturing of automotive products are very few, particularly in the Indian context. Therefore, the current study suggests a framework of research hypotheses for returns and recovery in the car industry, as put forth by the schematic diagram presented in Figures 3.2 and 3.3.

The present study bridges this research gap and accordingly the hypotheses developed and then tested statistically were as follows.
H1. CE execution based on the I4.0 tools is significantly affected by the perception of automotive manufacturers.

H2. CE execution based on the I4.0 tools is significantly affected by the perception of end-users of vehicles.

The model of the conceptualized hypothesis is illustrated graphically as given in Fig 3.4.

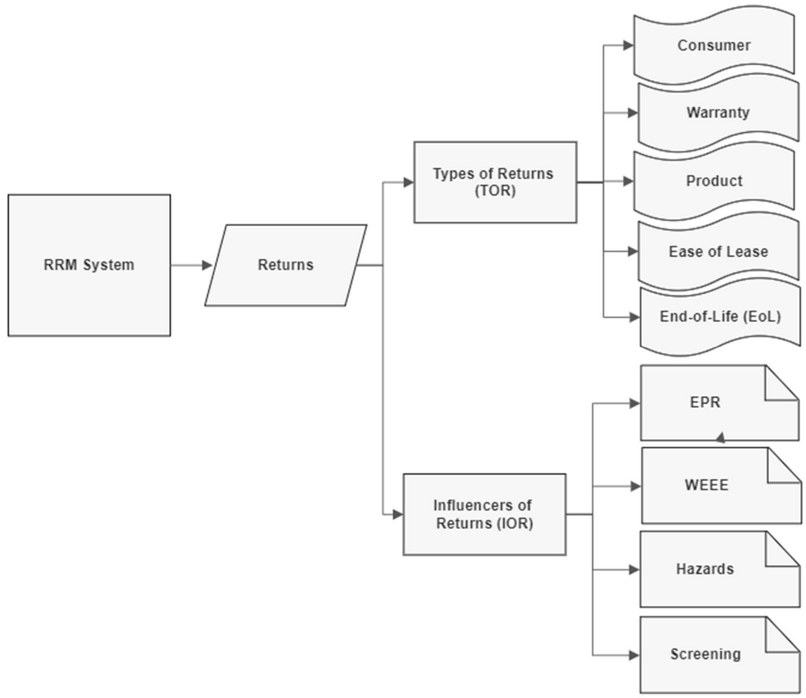
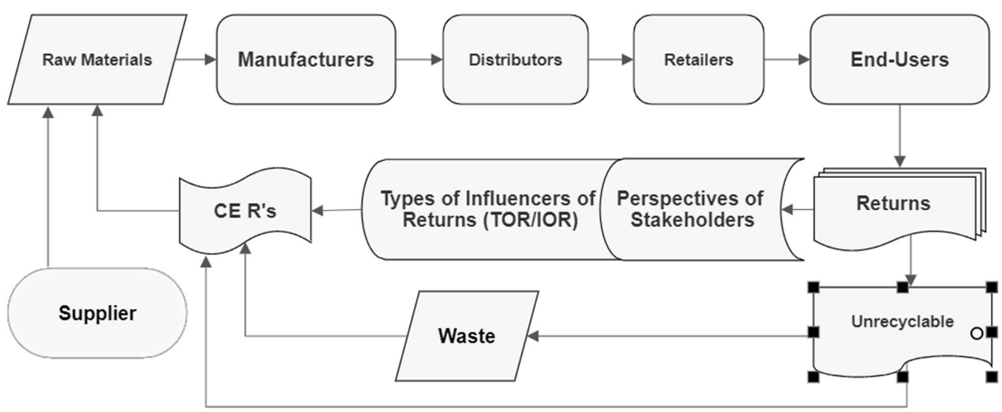


Figure 3.2 The list of variables of 'returns' of the products and parts of the automotive industry, considered under TOR and IOR in the present study



(R's of CE: Recycling/Remanufacturing/Reusing/Reducing/Refurbishing/Reclaiming etc.)

Figure 3.3 Role of the manufacturers and the end-users' kinds of the stakeholders of automotive industry and their perspectives on RRM under the shadow of the CE

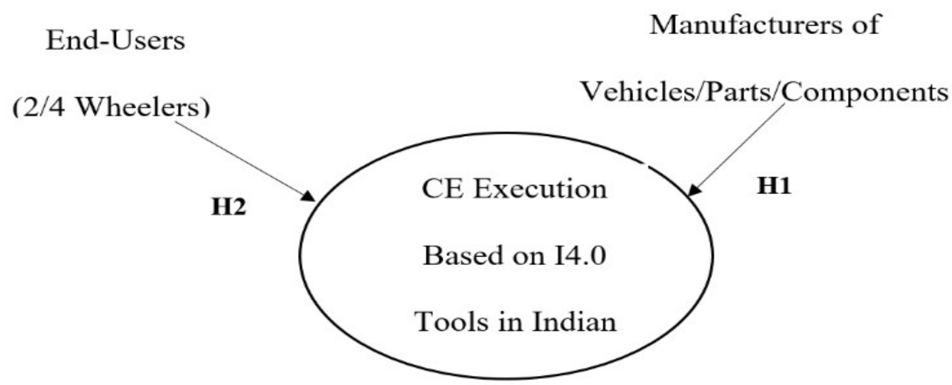


Figure 3.4 Model of the hypothesized relationships

Table 3.3 Enabling factors pertaining to the survey undertaken in the study (Q: Question)

Q-Code	*Enabling Factors*	*Q-Code*	*Enabling Factors*	*Q-Code*	*Enabling Factors*
T1	IoT in Asset Sharing	T8	RFID & IoT use in optimizing production	T15	RFID-equipped assets analysis by BD
T2	Reducing waste by going digital	T9	RFID use in IoT-enabled smart shops	T16	RFID & BDA use in reused materials tracking
T3	BD in Predictive maintenance	T10	IoT & RFID use in machine tool	T17	BDA use in new strategies' implementation.
T4	Intelligent devices supporting CE	T11	BDA use on post-consumed products	T18	BDA use in adaptive calibration
T5	RFID use in 'Re-use' CE strategy	T12	BDA use in Waste Stream Analysis	T19	BDA use in data from multiple machines
T6	RFID use in Data storage	T13	BDA & Reuse in recovery of ELVs	T20	BDA use in material flow closing
T7	RFID tags in unexpected events	T14	BDA use in traceability		

- *Research methods and analysis*

In the following sections details of the data collection, the hypothesis testing methodology, and data analysis are presented in a systematic manner.

Data collection: research instrument, sampling method, and the respondents' profile. The research instrument (questionnaire) was designed and structured by consulting the literature by consulting professional experts from the mechanical engineering and IT fields. Responses were sought, through the questionnaire (Appendix-II) from the two concerned stakeholders of the automotive industry on a 5-point Likert scale with 5 ('strongly agree') to 1 ('strongly disagree') kinds of responses. The instrument was uploaded via Google forms and shared on social media sites like Facebook, Twitter, LinkedIn, and Instagram. The collection of data from the participating respondent stakeholders remained scattered over around 3 months period during the 2019 Coronavirus days and therefore the 'Convenience sampling' method (Shrestha, 2021; Lisa, 2008) was employed in order to approach the respondents. The reliability of the research instrument was tested through Cronbach's Alpha which assumes that the multiple items of the questionnaire measure the same underlying effects of various constructs pertaining to the phenomena involved. The Average Variance Extracted (AVE) measures convergent validity while the Composite Reliability (CR) provides an idea about the variance shared by the observed and unobserved variables. Out of the 200 manufacturers and more than 600 automotive-users, contacted, 98 manufacturers and 294 end-users responded. The manufacturers' sample was collected particularly from the middle and top-level managers for the study (Shrestha, 2021). For the automotive parts/components, small and medium enterprises, having dominance in India, were selected while the vehicle manufacturers kind of respondents were from the top-of-the-line in terms of the market share. The end-users were either engineering or IT graduates as shown in Appendix-II. The response-making status was about 49% and 48.8% respectively from the automotive manufacturers and their end-users. As desired by them, the responses of the manufacturers were kept confidential.

- *Hypothesis testing methodology and data analysis*

The hypotheses structured, as stated earlier was tested statistically through the Factor Analysis (FA) technique that is based on the three primary procedures (Shrestha, 2021). It involves firstly checking the data appropriateness for the FA technique. Secondly, the extraction of the factors, and thirdly, the rotation of factors and their interpretation. In the context of the first step, the size of the sample and the relationship strength of the items in the instrument are discussed. Generally, the larger the sample size better would be the results of the FA. However, in case of higher loadings for the variables, even smaller sizes of the sample might be sufficient for the FA, whereas a value of the coefficient of correlation higher than 0.3 indicates good strength of the relationship (Awan & Sroufe, 2022). Also, for sampling adequacy, the KMO test provides the tool for testing the suitability of the data for FA application. If the sample size is less than 300, average communality values for the retained items are required to be tested. If it is less than 100, an average value larger than 0.6 is acceptable (Shrestha, 2021). To find the significance of the relevant constructs EFA was applied using IBM SPSS 23.0. The EFA being exploratory does not make any difference in the dependent and independent variables. Later, CFA was carried out to find the best fit model using IBM SPSS Amos 26.0 which was used for MLE (Maximum Likelihood Estimation) (Knauf Industries, 2021). Its requirement is to sample data from the multivariate normal distribution which might not be always true. However, it is suggested that the assumption of normality becomes important only if the findings are to be generalized, and in absence of any closed-form solution availability, iterative methods are recommended (Collier, 2020). Regarding the presumptions established and their justification in the current study, it should be mentioned that factor analysis (FA: exploratory and confirmatory) was the research technique used. This method makes the assumption that all the parameters are somewhat correlated. It should be highlighted in this context that the perception data was gathered from certain manufacturers and end customers. Additionally, the sample size should be bigger in theory for FA, although a ten to one ratio is suggested as an acceptable range (Shrestha, 2021). In the instance of a breach of this criterion, the recommended iteration approach was used in the current task. EFA yielded the unobserved variables called factors and thus the model was structured through Pearson's correlation. Bartlett's Sphericity Test was employed to examine the 'homogeneity of variance' and the KMO test was used for measuring the variance proportion among the factors with the same variance levels while using the scale: 0–0.49 as unacceptable; 0.89 as meritorious, and 0.9 to 1 as marvellous. During the EFA application, the 'Scree method' was employed for the retention of the factors. For the estimation of the R-squired values, PCA was employed with the 'Varimax' rotation. Finally, the results of the EFA were confirmed by applying CFA (Sangdaobooks, 2022) through which, for precise reflection of the constructs by observed variables, the reliability, and validity of the scale were determined by Cronbach's Alpha.

(c) Research methodology employed in RRM-related research

In order to test the hypothesis stated earlier, data were collected, analyzed, and results obtained following the methodology described below.

- *Data collection: design of the research instrument and profiles of the respondents and sampling procedure*

As stated earlier, data pertaining to the perspectives of the Indian auto industry stakeholders under reference were collected through a research instrument (a questionnaire) designed for this purpose. as presented in (Appendix-III). The stakeholders' responses were obtained on a 5-point Likert scale of 5 ('strongly agree') to 1 ('strongly disagree'). The kinds of returns selected in the questionnaire were in the form of the standard terms used by researchers as reported in the literature and discussed in this paper elsewhere (Section 2).

Primarily, these queries that the respondents of both kinds of stakeholders faced were either based on the 'TOR' or 'IOR' impacting the RRM of the automotive parts and the vehicles, as put forth in Table 3.4. Google Forms was employed for uploading the questionnaire, and sites such as Twitter, Facebook, Instagram, and LinkedIn were used for contacting the stakeholders' responses for the present research. For testing the reliability of the instrument, the statistic Cronbach's Alpha was employed. It is based on the assumption that various question items assess the same impacts of the various kinds of returns and other factors affecting the returns. Also, the AVE (Average Variance Extracted) measure was employed for the estimation of the convergent validity.

Table 3.4 'Types of Returns (TOR)' and 'Influencers of Returns (IOR)' and the associated Question (Q)-Codes

Types of Returns (TOR) [Q-codes]:	Market (MKT) [M2/U2]	Consumer (CNSMR) [M3/U3]	Warranty (WRRNTY) [M4/U4]	Product (PROD) [M5/U5]	Ease of Lease (LSE) [M6/U6]	EOL [M7/U7]
Influencers of Returns (IOR) [Q-codes]:	*The influencer RRM Program for returns of parts/products.* (RRMP) [M1/U1]	*The influencer EPR* (EPR) [M8/U8]	*The influencer WEE* (WEE) [M9/U9]	*The influencer Hazards* (HZ) [M10/U10]	*The influencer Screening* (SCREEN) [M11/U11]	-

In terms of the sampling methodology, the 'convenience sampling' (Shrestha, 2021) procedure was employed for contacting more than one hundred manufacturers and around 500 customers from the Indian automotive industry. Out of those contacted, only 96 manufacturers and 294 end-users submitted their responses. Among the manufacturers, only those were contacted who had a presence in the Indian market (SIAM, 2022). On the other hand, the second kind of stakeholders were the end-users of automotive industry products and parts, belonging to the Delhi-NCR region. Most of them were educated people, as shown in their profiles' data presented in Appendix-III. Most of the manufacturers preferred that their data be used only for research purposes and requested that their identification not be made public.

- *Methodology for hypothesis testing and data analysis*

As stated earlier, the hypotheses for the present research were structured, and statistical procedures called factor analysis (FA) were employed for their testing. According to Shrestha (2021), FA involved the following steps: (a) appropriateness of data check; (b) factor extraction; and (c) factor rotation. As regards the testing of the data's appropriateness for the application of FA, the KMO (Kaiser Meyer Olkin) test was employed. Since the sample sizes for the two kinds of stakeholders, manufacturers and end-users of the automotive industry, considered in the present study were respectively less than 100 and 300, the appropriate guidelines recommended by Shrestha (2021) were employed. Specific types of returns, TOR and IOR, in the automotive industry were studied through the literature, as specified earlier (Tables 3.11 & 3.12). Thereafter, their importance was determined through EFA. The dependent and independent variable differentiation is not made by the EFA, as it is only exploratory in procedure. The well-known software IBM SPSS 26.0 was employed for this purpose. According to Collier (2020), it was used for the MLE (Maximum Likelihood Estimation), which enables multivariate normality in data that sometimes may not be true, and then the iteration procedure is adopted. In the next phase, the best-fit modelling was undertaken through another statistical tool called CFA using IBM SPSS Amos 26.0 software. EFA yielded the unobserved variables called factors, and thus the model was structured through CFA. Bartlett's Sphericity Test was employed to examine the 'homogeneity of variance, and the KMO test was used for measuring the variance proportion among the factors with the same variance levels while using the scale: 0-0.49 as unacceptable; 0.89 as meritorious; and 0.9 to 1 as marvellous. For the estimation of the R-squired values called communalities, PCA was employed with the 'Varimax' rotation. Finally, the results of the EFA were confirmed by applying the CFA, through which, for precise reflection of the constructs by observed variables, the reliability and validity of the scale were determined by the statistic named Cronbach's Alpha.

3.4 Concluding words

The contents of this chapter (Chapter III) comprise of the methodologies of the research that were employed in all the five investigations in the present research. To sum up, fist the two investigations which involved the literature survey were based on the 'content analysis' kind of research methodology. The third study related to CE-BT employed the recently evolved 'BWM' technique.

The CE-I 4.0 related investigation employed the factor analysis (FA) while the last study, the RRM related, is based on the FA and cluster analysis tools of research. All these tools and methodologies are detailed as discussed in the above-given sections of this chapter.

The next chapter (Chapter IV) presents the details pertaining to first study the literature survey-based explorations undertaken in this research.

CHAPTER IV

STUDY OF INDIAN AUTOMOTIVE INDUSTRY FROM THE CE PERSPECTIVE

4.1 Purpose

To study through a content-based systematic literature review how the circular economy (CE) and its respective components' applications impacted the automotive industry and what is the future scope of research in the concerned fields.

4.2 Method

Research methodology employed was 'content analysis'. The details of the methodology are presented in the previous chapter (Chapter III).

4.3 Results

Evaluation of the concerned reviewed material was undertaken by the authors by way of following the same testing procedure which they had adopted in their earlier research works (Singh, Chakraborty, & Roy, 2018; Rizvi *et al.*, 2021). The results of the related spreadsheet indicated that concerned parameters were within acceptable limits concluding thereby that inter-coder reliability, which is the most important yardstick of reliability, is sufficient for the present work.

The matter content to be reviewed in the present work was collected and 'content analysis' methodology was employed through the application of all of its four components as per their details given above. In the process, the literature was categorized and the respective proportionate contributions were computed and illustrated as follows.

All the ‘units of analysis’ which constituted the reviewed literature were screened in light of the above stated characteristics of the categories and results were obtained as illustrated through the radar diagram presented in Fig 4.1. Computations were made to know in what proportions the characteristics/features of different structured categories contributed to the reviewed literature and results were obtained as shown in Table 4.1. Most of the contents presented in Table 4.1 are self-explanatory. It might be noted that maximum contribution from the category “source” came through its characteristic ‘journals’ (73.62 %) while minimum came from ‘conferences’ (9.82 %). The corresponding figures of maximum/minimum contributions from other categories i.e., from publication time, typography, thematic areas/sub-areas, study tools were respectively found to be from their respective characteristics as follows:

From publication time: 2015 and earlier (22.09 %) and 2021 (6.13 %); from Typography: Review-oriented (36.81 %) and Application-oriented (25.77 %); from Thematic areas: CE and its Components (41.72%) and ELV Concept and CE (12.88 %); from Study Tools: Non-Analytical: (Qualitative) Tools: 58.9 % and Other Tools (e.g., software-based tools etc.) (7.36%). These findings are discussed below:
According to Seuring & Gold (2012), the research methodology named as ‘content analysis’ provides a dependable research tool for conducting the business of reviewing the academic matter-contents which belong to the unstructured or qualitative forms. As the present work also pertained to the same nature of the matter-content all the steps of the said research methodology were followed and results were obtained as given above. In all, there were five categories each associated with their respective characteristics. Under the ‘source’ category, maximum contribution came from the characteristic ‘journals’ which makes the reviewing process much more valuable and richer. The richness of the present work can be attributed to the well-established globally accepted fact in the world of academics that most valuable researches are published in journals, of course, with those having good repute and high impact factors.

As regards the category ‘publication time’, maximum contribution (22%) came from the ‘Type-8’ characteristic for the publications of the year 2015 and earlier. On the other hand, almost 70% of the matter reviewed represented the research work undertaken in the period of just the last 5 years (2018-2022) and this implying thereby the fact that most of the matter content pertaining to the present work represents the latest developments in fields associated with the topic under reference. In terms of the category ‘typography’, maximum contribution came from the characteristic ‘Review’ kind of publications. This approximately equalled the ‘research’ type characteristic and contribution of both the characteristics i.e., ‘review’ and 'research’ together emerged to be more than 70%. Once again it indicates the strength of the coverage of the kind of the matter content undertaken in the present work. From the next category i.e., the ‘thematic areas’, maximum contribution (around 42%) came from the characteristic ‘CE and its components’ whereas the respective nexus of the themes CE-ELV and CE-IT (Information Technology) contributed minimum.

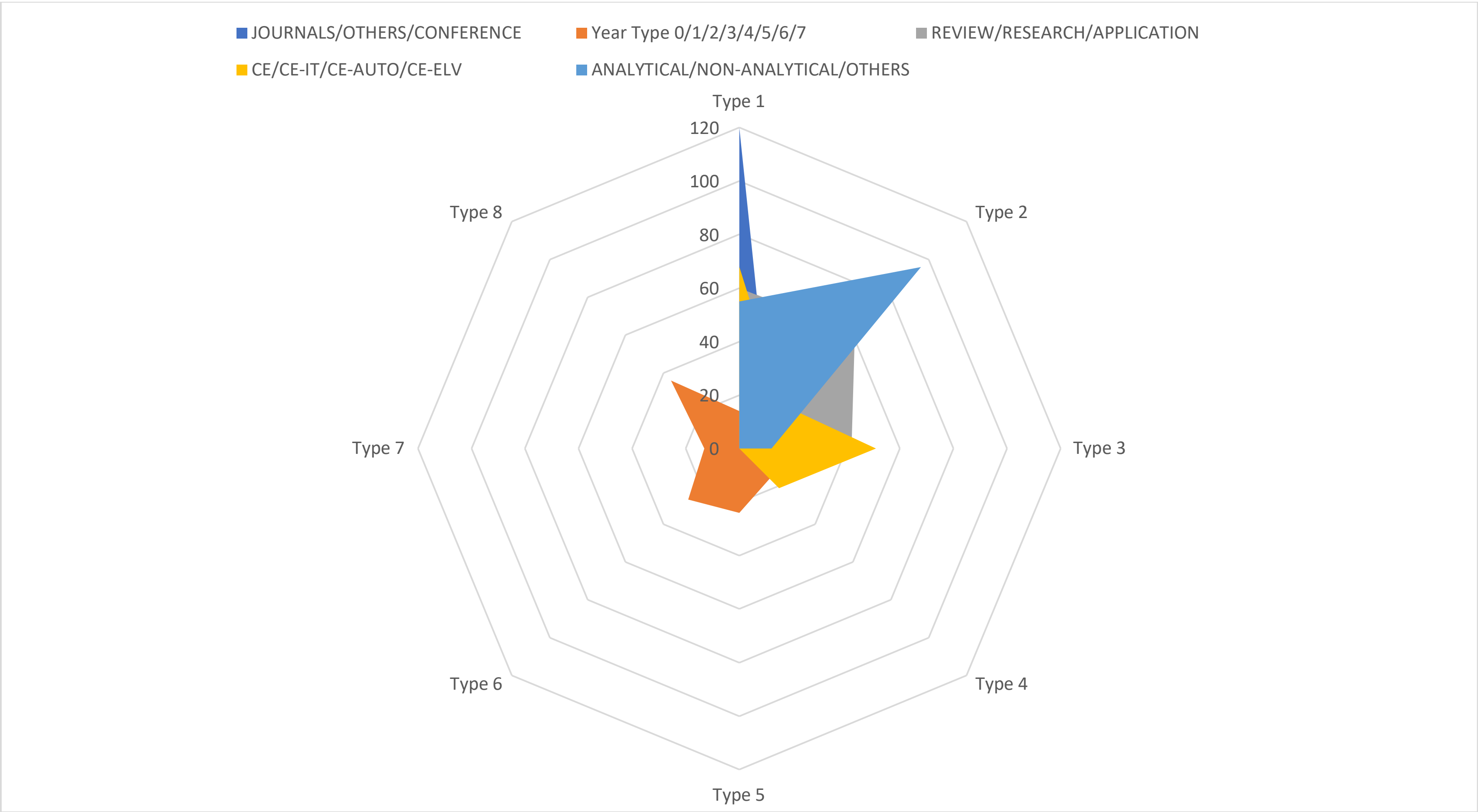


Figure 4.1 Radar diagram for the analysis of the 163 reviewed work data under five different structured categories.

Table 4.1 Contribution (in %) to the reviewed matter by characteristics/features for content analysis

Type #	*Characteristics/Features (of reviewed matter)*	*Units of Analysis (papers/documents) (in nos.)*	*Contribution (in %)*	*Maximum Contribution (in %) (of the category)*	*Minimum Contribution (in %) (of the category)*
Category (A): Sources of the reviewed literature					
Type-1	Research Journals' Papers:	120	73.62	73.62 % (Journals)	
Type-2	Conference/Seminar/ Webinar Papers:	16	9.82		9.82 % (Conferences etc.)
Type -3	Other Research based materials (e.g., company/industry documents)	27	16.56		
Category (B): Publication Time of the reviewed literature (Year)					
Type-1	2022 Publications	14	8.59		
Type-2	2021 Publications	10	6.13		6.13% (2021 Publications)
Type-3	2020 Publications	23	14.11		
Type-4	2019 Publications	16	9.82		
Type-5	2018 Publications	24	14.72		
Type-6	2017 Publications	27	16.56		
Type-7	2016 Publications	13	7.98		
Type-8	2015 and Earlier Publications	36	22.09	22.09% (2015 and earlier publications)	
Category (C): Typography of the reviewed literature					
Type-1	Review-oriented	60	36.81	36.81 % (Review-oriented)	
Type-2	Research- oriented	61	37.42		

Type #	*Characteristics/Features (of reviewed matter)*	*Units of Analysis (papers/documents) (in nos.)*	*Contribution (in %)*	*Maximum Contribution (in %) (of the category)*	*Minimum Contribution (in %) (of the category)*
Type-3	Application- oriented	42	25.77		25.77% (Application-Oriented)
Category (D): Thematic Areas of the reviewed literature					
Type-1	CE and its Components	68	41.72	41.72 % (CE Components)	
Type-2	CE–IT Nexus	23	14.11		
Type-3	CE-Auto Nexus	51	31.29		
Type-4	ELV Concept and CE	21	12.88		12.88 % (CE-ELV)
Category (E): Study Tools utilized in the reviewed literature					
Type-1	Analytical Tools	55	33.74		
Type-2	Non- Analytical: (Qualitative) Tools	96	58.90	58.9 % (non-analytical)	
Type-3	Other Tools (e.g., software-based tools etc.)	12	7.36		7.36 % (Other Tools)

This implied a rich scope of the future research work in these interactive areas of the CE with the ELV (End of Life Vehicles) and IT. Such a status of knowledge might be verified by the fact that IT is passing through its infancy stage and therefore logically there should be a smaller quantity of such matter contents available to be reviewed. And so is the case also with the ELV that conceptually has only recently taken its birth and in practice, therefore, the nexus of CE-ELV is evolving an entirely new kind of production system called 'remanufacturing' that would be expected in future to go in parallel to the on-going system of 'manufacturing' with some structural transformation in the classical black-box model of the input-output constituents of the production system. It is in this background of the findings that the Type-3 characteristic of the thematic category i.e., the 'CE-auto' nexus was found to be next to the 'CE and its components'. As would be revealed by the matter contents which would be discussed in the next Section (Section 4), most of the developments reported under the CE-auto theme pertain to the developed nations only. On the other hand, the main auto products i.e., cars and two-wheelers are being extensively used in developing and underdeveloped countries also. This puts forth a high demand of research efforts to be shouldered by the future researchers in the field of CE-auto, especially with reference to the developing and underdeveloped nations of the world.

Finally, the result pertaining to the last category i.e., 'study tools' revealed that maximum number of the reviewed research works (59%) employed the kind of the characteristic 'Non- Analytical: (Qualitative) Tools', whereas very few research works (less than 10 %) reviewed were based on the kind 'Other Tools' (e. g. software-based tools etc.). Implications of such a finding are that currently, not many research publications are employing quantitative tools and still lesser researchers are utilizing the software-based tools in their investigations. This indicates that there is a wide scope of the employment of analytical tools and IT tools in the researches to be undertaken in the days ahead.

4.4 Discussion and conclusions

As stated earlier, the RP (research problem) in the present study was: 'Have the circular economy and its respective components' applications impacted significantly the automobile sector and what is the future scope of research in the concerned fields?'. In order to search for an answer to this RP, in light of the already detailed research methodology (Chapter III), an effort was made to collect and analyze the relevant literature base and review the collected data as presented in Chapter II under different thematic areas, titled as Circular Economy (CE) in auto sector, Remanufacturing in auto sector, CE-IT Nexus in auto sector, and CE-ELV (End-of-Life Vehicle) Nexus. Results were obtained as presented in Chapter IV. In this section, the already reviewed matter-contents are discussed as follows:

In light of the reviewed matter contents, the issues for future researchers in the form of 'research gaps' and 'challenges ahead' were identified and the same are presented in a systematic manner in what follows. Today this has become a global fact that automobile engineering in most parts of the world is a very significant job-generating sector for governments. In light of such developments, the auto manufacturers are getting legally bound to follow the rules and regulations of their respective countries set from pollution control and safety measures points of view.

Thus, future manufacturers of automobiles are getting ready for higher investments in R&D in order to cater to the demands of the day pertaining to cleaner technologies, environmental protection, societal obligations, and conservation of natural resources by way of adopting measures for CE. One major problem today's auto sector is encountering in the CE arena is the cost of recycling, which might be higher than the cost of extraction of resources. Despite many such impediments, according to Rommel (2018), the future auto industry would still get benefitted from the CE applications. To be specific, on the basis of the extensive literature search following issues, demanding the attention of future researchers were found:

(i) From a sustainability point of view, solutions pertaining to the health and environmental risks associated with automobiles would have to be searched by way of responsible innovative technologies of recycling and reusing the older vehicles in order to make new ones. Such strategies would demand applications based on digital technologies/AI/modular design/analytics and machine-to-machine communication.

(ii) Last few years have witnessed expanding technological situations where modern IT tools are getting widely used. However, it was found that applications of the tools like Big Data analytics, etc. are yet to cross the infancy stage (Jain *et al.*, 2017). Thus, there appears to be a wide scope for exploring this field of CE-IT nexus, particularly, in the auto sector.

(iii) Remanufacturing is presently on the path of getting shaped into a field like that of the traditional field of manufacturing. So far as the auto sector is concerned, only 5-6 locations in the world are involved in such endeavours.

(iv) Automobiles need to be redesigned from the consumer perspective angle, particularly, when the framework of the real-life CE applications is considered as reflected by the model of Lewandowski (2016).

(v)The mathematical models are being developed extensively by researchers for varieties of real-life applications. In future processes of modelling, it is needed to incorporate the variable 'uncertainty' also in researches, particularly, when employing quantitative approaches in the field of CE-auto sector of tomorrow.

(vi) It was found that Big Data employment in the CE field is based on huge data (Davenport *et al.*, 2017) and also there are many barriers in the way (Galvao *et al.*, 2018), thereby making it difficult and challenging in its application (Mieras, 2016).

Despite these facts, Hossfeld (2017) observed that Big Data applications make a key success factor in the manufacturing field of tomorrow provided that, according to IFU (2018), it is employed on the step-by-step criteria. This implies that the IT tools would have big role in the success of future manufacturing and remanufacturing activities of the auto industry also. Bressanelli *et al* (2018) also opined that challenges encountered in CE-auto sector can be met with success by the applications of digital tools. Some more areas related to the research gaps are presented in Table 4.2.

Future researchers might address these issues in the days ahead. So far as the challenges are concerned, it is worth noting that more and more precious and valuable natural resources are getting scarcer day by day. From material resource viewpoint, predictions indicate an 8-fold enhancement in its consumption by the year 2050 (EC, 2019). Research works in the field of CE-IT nexus is highly promising so far as the regenerative nature of the economy is concerned (Moreno *et al.*, 2016).

Table 4.2 Research Gaps presented in a summarized form.

Research Gaps	*References*
In China, the used electric vehicles' power batteries' recycling provides a big challenge in the auto sector in the days ahead.	Tang *et al* (2018), Sovacool *et al* (2020), Liu *et al* (2020), Bonsu (2020)
Electric vehicle market needs to be paid more attention by the future manufacturers of the auto sector especially in China where it is termed as 'Low carbon Transport'.	Kieckhafer *et al* (2016), Liu *et al* (2011), Gupta *et al* (2022)
Innovative efforts are required to be made in auto sector by way of designing the vehicles from behavioral science viewpoint.	Williams (2006)
In the context of EOL, environmental protection awareness has to be generated and emphasized.	
With the ongoing high production rate of automobiles, a certain number of them would have to be disposed of, keeping the rate of manufactured vehicles in view.	
From the waste management perspective, stockpiling of the auto industry scrap has to be minimized in order to protect the environment, making traffic safer and initiating for better utilization of natural resources and energy sources.	Zhaoanjian *et al* (2014), Patel and Singh (2022)
From the viewpoint of the recovery of the cobalt and nickel kinds of precious metals from the Li-ion batteries' it is worth noting that the coming decade or so would be demanding high quantity of such batteries and therefore research on their recycling would have to be undertaken in the future.	Steward *et al* (2019), Ortego *et al* (2020), Bonsu (2020)
More attention should be on scrap car recycling management.	Steward *et al* (2019)
Future research issues should include reverse logistics (RL) implementation and to improve management of EOL, particularly under the shadow of the immense competition in the automobile consumer market.	
It appears that there is good scope of research in the CE-auto field.	Tseng *et al* (2018), Patel and Singh (2022)
There is a need to develop models based on minimized level of linear thinking in CE since every element impacts another.	Buruzs *et al* (2017)
Studies on barriers identification for economically and ecologically befitting digital platforms are needed.	Berg *et al* (2019), Rizvi *et al* (2021)

Research Gaps	*References*
In both cases, be it capturing the transfer of goods in manufacturing processes and the process to identify the micro components in a blockchain, would be utterly important in the future.	Leng *et al* (2020), Rizvi *et al* (2022)
The very first of its kind and the only standard pertaining to CE, the BS-8001:2017, appears to remain 'vague', in terms of the provision of the guidelines for the control and application of the CE in industrial environments.	Pauliuk (2018)
There appears to be a wide gap in 'economic circularity' at the global level. It was reported to be around 9.1 % only at present.	Blanca *et al* (2019), Goncalves *et al* (2022)

The technological world of tomorrow would not be based on conservation of resources, but it would have to be designed for circulation and recirculation of resources and from this viewpoint the auto industry, like other sectors, would demand a more collaborative and supportive kind of relationship with its future customers. As far as possible the innovative kind of auto product development would have to be visualized enabling different components of CE, e.g., recycling and remanufacturing easier. An extensive review of literature indicated some potential challenges in the days ahead. Table 4.3 presents some of these challenges as demonstrated by their respective authors.

Table 4.3 Challenges encountered in the fields of CE, e-mobility, ELV and auto Sector

Issues	*Some Potential Challenges*	*Authors*
Regarding E-Mobility	The next decade of technological progress would be witnessing newer forms of E-mobility systems from economic sustainability and better material utilization viewpoints.	Buruzs *et al* (2017); Tyagi and Vishwakarma (2022)
Regarding ELV	Number of the ELVs are getting multiplied day by day with the ever-growing upward trend of the manufactured number of vehicles in the global market.	Saidani *et al* (2017); Xion (2021)
	At the ELV stations, searching for innovative material separation and material recovery technologies would appear to be big challenges of tomorrow.	Buruzs *et al* (2017)
	As the production of local vehicles increases the impact of ELV wastes to the environment will also increase.	Amelia *et al* (2009)

Issues	*Some Potential Challenges*	*Authors*
	Disposal of the available material and other resources in the ELV context would demand newer quantitative tools based on the MCDM (Multi Criteria Decision Making) etc. for more efficient and scientific handling of the waste management.	Wang *et al* (2018)
	The residual value evaluation and value recovery appear to be highly promising topics for future explorations.	Jiang *et al* (2018); Hatcher *et al* (2013); Liu *et al* (2018); Kurilova-Palisaitiene *et al* (2018); Wróblewski and Lewicki (2021)
	In terms of the ELV constituents' disposal the shredder residue makes a critical item for future consideration in the auto industry.	Khodier *et al* (2017); Vijayan *et al* (2022)
Regarding Automobile Industry	In the Indian context, not much is known about its ELV status due to its informal nature. As a result, there exists a wide scope for exploring Indian ELV market.	CPCB (2015)
	Under the highly competitive auto markets there are important challenges like environmental and economic sustainability factors in the CE-auto nexus trade.	Xin (2016); Patel and Singh (2022)
	Designing automobiles supporting the CE concept for sustainability by way of adopting the customized recyclability in its ELV tenure.	Rommel (2018); Yu *et al* (2022)
	The Indian auto industry needs to be revisited for adopting sustainability in the products and its parts to enable these to demonstrate the sustainability performance.	Kumar *et al* (2015); Mathivathanan *et al* (2022)
	While designing for light-weight vehicles, magnesium parts are being employed. These have to be explored from environmental considerations' viewpoint.	Tharumarajah *et al* (2006); Golroudbary *et al* (2022)
	Both in the Chinese and the Malaysian auto industry, the reverse logistics were recently analyzed and this indicates future scope in the field.	Zhikang (2017); Fernando, Shaharudin, & Abideen (2023)
	Not many studies have been undertaken in the past on the applications of the sustainability strategy in the industrial sectors. This implies future scope of work in the auto sector also.	Engert *et al* (2016a); Engert *et al* (2016b); Santos and Proenca (2022)

Issues	*Some Potential Challenges*	*Authors*
Regarding CE in Developing Countries	Limited infrastructure for transportation of wastes; Non availability of the data on CE pertaining to the SMEs; Poor knowledge regarding CE in the supply-chain constituents; Poor regulatory provisions and weak organs/agencies responsible for reinforcement of the laws framed by the governments.	Preston *et al* (2019); Ahmed *et al* (2022); Mishra *et al* (2022)

Sivakumar (2014) reported that cars are driven for 15-20 years in India until they reach the scrap dealers, to be shredded and their innards reused with almost no regard for the environment. As the number of new cars piling up because of loads of newer models introduced in the Indian market, more modern facilities are needed for recycling and recovering materials of the EoL vehicles. In the month of August in the year 2011, a recycling unit was launched 55km outside Chennai, which may offer an environment friendly option for the reuse or disposal of automotive parts. The vehicle graveyards in India are full with scrapped vehicles its number is exponentially increasing. There are no regulations in India to deal with the disposal of such old vehicles when compared with Europe or certain Asian countries. In fact, the vehicle dismantlers in India seem to be more concerned about selling quality parts and components. Profitability isn't affected by the material composition of the parts and the components if the customer remains satisfied with the used part/component. However, the developed nations practice a different tradition than this one. Also, in India, the lack of consideration for Government interactions in the sustainability of vehicles is evident, and no such regulations and directives like those in Europe regarding End-of-Life Management of Vehicles (ELMVs) are present, which can cause designers to consider effective automotive recovery at the design stage. India, similar to other nations, possesses significant potential to repurpose or recycle end-of-life vehicles (ELVs) into materials and energy, thereby reducing the use of non-renewable resources and minimizing ELV landfilling. It is estimated that about 70% of an ELV is dismantled and reused in India as a secondary resource or sold to original equipment manufacturers. Except a few basic principles in the environmental pollution control policies, India doesn't have a stringent ELV handling policy unlike Korea, Japan and EU. As a result, Indian automobile industry mainly consists of a hugely unorganized ELV handling system including sales, which remains unmonitored and largely unscientific.

The next chapter (Chapter V) presents the details pertaining to second study of the literature survey-based explorations undertaken in this research.

CHAPTER V

STUDY AND ANALYSIS OF CIRCULAR ECONOMY IN AUTOMOTIVE INDUSTRY UNDER THE IMPACT OF IT TOOLS

5.1 Purpose

To study through a content-based systematic literature review how the CE and Reversed Supply Chain Logistics (RSCL) nexus changed under the impact of the IT tools and their applications'

5.2 Method

The research methodology employed for the present investigation was as discussed earlier in the Chapter III.

5.3 Results

The analysis of the collected data, in this context yielded the summarized information presented in the bar chart (Fig 5.1).

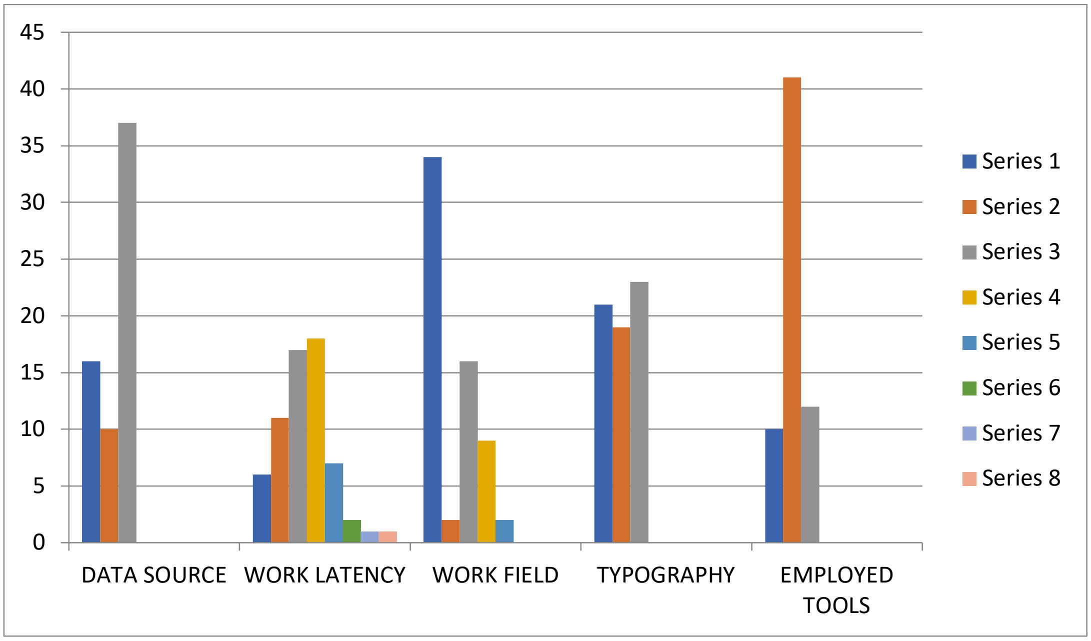


Figure 5.1 Analysis of the reviewed work-data, numbering 63 (y-axis), under 5 different categories (y-axis)

- *Material Evaluation and Research Quality Phase*

Primarily this phase involves inter-rater reliability involving at least two coders, testing for transparency and objectivity based on clear coding schemes and validity based on theoretical foundation (Seuring & Gold, 2012). Following the methodology of testing the reliability, the transparency and validity, detailed by Agrawal, Singh, & Murtaza (2018), the data reviewed were classified by researchers and consensus was ensured. For reliability, all the literature-related components (e.g. journals etc), were cross-checked through spread-sheets and the results were found to be within acceptable limits implying thereby reliability and consistency of the present research. The data-set pertaining to the present work were collected and analyzed as given in the earlier sections.

The following section deals with the results obtained in terms of the findings contained in the content-based analysis of the collected data, presented as follows:

- *Reviewed data work about 'Data Source'*

The reviewed data work originated from the following sources: 'journal publications', 'company/industry reports and documents' and 'conference/workshop proceedings'. The content- based analysis is presented in Table 5.1. It may be observed that maximum contribution (58.73%) came through the journals' publications and next to it (25.4%) was from conference/workshop proceedings, while company reports and documents contribution was only 15.87% to the reviewed material.

Table 5.1 Content-based analysis of the reviewed matter pertaining to 'data source'

Data Source Series No.	*Data Reviewed (No. of Papers)*	*Percentage (%)*
1: (Journal Publication)	37	58.73
2: (Company/Industry Reports and Documents)	10	15.87
3: (Conference/Workshop. Proceedings)	16	25.4

- *Reviewed data about 'Work Latency'*

The reviewed data work originated from the publications during the years 2019, 2018, 2017, 2016, 2015, 2014, 2012 and 2010. The content-based analysis is presented in Table 5.2.

Table 5.2 Content-based analysis of the reviewed matter pertaining to 'data work latency'

Data Work Latency Series No.	*Data Reviewed (No. of Papers)*	*Percentage (%)*
1: (Publication year 2019)	6	9.52
7: (Publication year 2018)	11	17.46
7: (Publication year 2017)	17	26.98
8: (Publication year 2016)	18	28.6
8: (Publication year 2015)	7	1.11
6: (Publication year 2014)	2	3.17
7: (Publication year 2012)	1	1.58
8: (Publication year 2010)	1	1.58

It may be observed that maximum contribution (28.6%) to the present reviewed matter came through the works published during 2016, next to which (26.98%), was from the year 2017 while the works of the years 2019 and 2015 were almost in the same proportion and 2012, and 2010, each respectively contributed minimum (1.58%) to the reviewed material.

- *Reviewed Data about 'Work Fields'*

The reviewed data work was analyzed on the basis the work fields/areas to which the reviewed matter content was associated with. The analysis revealed that the entire data-set got originated from the following fields/areas of knowledge: 'circular economy (CE)', 'reversed supply chain logistics (RSCL)', 'digital technology (DT)', 'CE-DT Nexus' and 'RSCL-DT Nexus'. The content-based analysis is presented in Table 5.3.

Table 5.3. Content-based analysis of the reviewed matter pertaining to data work fields /areas

Data Work Field Series No.	*Data Reviewed (No. of Papers)*	*Percentage (%)*
1: (Circular economy, CE)	34	53.96
2: (Reversed Supply Chain Logistics, RSCL)	2	3.17
3: (Digital Technology, DT)	16	25.4
4: (CE-DT Nexus)	9	14.3
5: (RSCL-DT Nexus)	2	3.17

It may be observed that maximum contribution (53.96%) came through the circular economy (CE) field, next to which (25.4%) was from the digital technology (DT) area while CE-DT area contributed around 14 %. The RSCL i.e., 'Reversed Supply Chain Logistics (RSCL)' and 'RSCL-DT (Digital Technology) nexus' data each contributed minimum (3.17 %) to the entire data-set containing the reviewed material.

- *Reviewed Data about 'Typography'*

The reviewed data work analyzed in terms of the 'typography' originated from the following types of data work: 'research', 'applications and 'review' types. The content-based analysis is presented in Table 5.4.

Table 5.4. Content-based analysis of the reviewed matter pertaining to 'data work typography

Data Source Series No.	*Data Reviewed (No. of Papers)*	*Percentage (%)*
1: Research	21	33.34
2: Applications	19	30.15
3: Review type	23	36.51

It may be observed that the quanta of contribution to the reviewed matter content through the 'research' and 'applications'-based matter was almost same whereas 'review' types data contributed maximum (36.51%) to the reviewed material.

- *Reviewed Data about 'Tools Employed'*

The reviewed data work was also analyzed in light of the kinds of analytic tools employed by different authors of the works included in the present review. It was found that the works, under reference, involved following kinds of analytic tools: quantitative tools, qualitative tools, and digital technology-based tools. The content-based analysis is presented in Table 5.5

Table 5.5. Content-based analysis of the reviewed matter pertaining to 'employed tools'

Employed Tools Data Work Series No.	*Data Reviewed (No. of Papers)*	*Percentage (%)*
1: Quantitative tools	10	15.87
2: Qualitative tools	41	65.08
3: Digital Technology-based tools	12	19.05

It may be observed that maximum contribution (65%) came through the employment of the qualitative tools, next to which were 'quantitative-' and 'DT-based' tools, which were employed by the researchers, were 15.87% and 19.05% respectively.

5.4 Discussion and conclusion

In light of the results obtained, the findings of the present study are discussed. It has been observed by researchers that literature review based on content analysis might serve as a good technique of research while dealing with the qualitative and unstructured data and other materials (Seuring & Gold, 2012). They also noted that 'content analysis may also be applied for analysing published material'. Accordingly present research was undertaken in terms of five categories of the data reviewed and results were obtained. In the category of the 'data source', it appears that majority of research material is originating from the journal-based resources. It appears to be logical also because the world of academia and researchers cannot survive without the research material made available by the journals. Thus, journals appear to be a widely consulted source of data and information among the academic people. As regards the second category viz. latency of publication, it appears that during 2016 and 2017 researchers paid much more attention to the topic under reference, However, it appears that prior to 2016, not many researches were interested in the field. As regards 2018 and afterwards, the data collected might not have accessed enough of the published literature due to the limitations of resources on the part of authors. For appropriate conclusions, in this context, future reviews would have to be referred to. In the third category pertaining to the academic field of the data, it was revealed that the CE emerged as the most researched field and so is expected to be in future also for obvious reasons of the material/energy getting scarcer day by day.

Similar observations were made by other researchers also (e.g., Suárez-Eiroa *et al.*, 2019). Moreover, under the shadow of the recent developments in field of digitization, future researchers are likely to pay more attention to the DT as well as the CE-DT nexus. This is the future requirement because, as stated earlier, the DT tools are found to be the CE enablers. So far as the Reversed Supply Chain Logistics (RSCL) is concerned, it appears that currently relatively this title is getting less attractive among the researchers as, perhaps, enough work has already been undertaken by the previous investigators on the topic. Through the findings pertaining to the fourth category viz. typography (research, review and application types data), it might be concluded that all the three types of works are being addressed by the researchers equally. Lastly, the findings on the fifth category i.e. the 'tools employed' revealed that mostly qualitative kind of researches were undertaken during the decade considered in the present work. Thus, future researchers would have to address the issues pertaining to the CE field more rigorously through 'quantitative' and 'DT-based tools' in their works. This is a direct implication of the present findings so far as the tools employed by researchers are concerned. As regards the discussion on the reviewed data, it might be noted that entire reviewed data analysis revolved around the research issue: how the areas of the CE and reversed supply chain logistics (RSCL) got impacted under the shadow of the emerging IT tools? Since the last century or so, companies have been constantly making efforts for developing goods and services for earning more and more profits. However, this process of profit making has not been effectuated in an optimal manner. One very important dimension of this non-optimality could be traced in terms of the 'waste' resulting from the used and consumed products/materials/energy that never came back to the original manufacturer/supplier of the entities.

Hannon *et al* (2016) observed that when a consumer uses a product infrequently or discards it because it has worn out, at least some of the material/energy that went into making the product has been wasted. Agrawal, Singh, & Murtaza (2018) in their case study of electronics manufacturer based in North India identified new challenges in managing product returns due to the changed business environment.

With the huge number of resources going into making of huge number of products, the precious treasure of available resources is getting scarcer day by day. The best course of action for resolving the scarcity issue in the future would be to maintain the resources associated with the product, such as energy, materials, and other components, in "circulation" at all times in order to minimize or completely eliminate "waste." Some businesses are using this kind of strategy under the banner of what is termed as 'Circular Economy (CE)'. The underlying idea behind CE is to create products which are durable, easy to reuse, remanufacture or recycle and, of course, profitable. Normally, companies do not bother today about what would be the ultimate fate of their products after they are procured by the end-users. It is anticipated that people will eventually throw them out and buy new ones, and the local waste collectors will take care of what has been discarded by the consumers. For example, in general, mechanical components are designed with the 'ease of manufacturing' in mind because this is what makes them (components/parts) less expensive. This leads to such 'design choices' like snapping pieces together rather than joining them with fasteners. A manufacturer may keep a policy of giving its customers rebates for returning end-of-life parts/products/mechanical components so that the manufacturer might be able either to refurbish them for resale at a lower price or entirely dismantle them for the purpose of recycling. According to a recent research, each year some $2.6 trillion worth of material in fast-moving consumer goods, 80 percent of the material value is thrown away and never recovered (Hannon, Kuhlmann, & Thaidigsmann, 2016). As reported in literature (Govindan & Hasanagic, 2018) by 2050, the demand for natural resources is expected to get tripled indicating thereby the exceeding importance of either elimination or minimization of waste which is the primary target of CE.

As we progress, the CE would have to effectuate a larger quantity of the material to be reused again in one form or the other. In this context, to cite a practical example, in Europe, it is estimated that the net benefit of applying circular-economy principles could be as much as €1.8 trillion annually by 2030 (Manyika *et al.*, 2015). It was also predicted that by 2020, up to 50 billion connected devices would be present in our technological world (Morlet *et al.*, 2016). Therefore, the firms that successfully design products from the 'circular economy' viewpoint would be of considerable value and would create everlasting and rewarding relationships with customers. However, the data pertaining to CE system appears to be huge and therefore the success of CE and its operation would primarily depend on the extent to which IT tools are employed. So is the case with the scope of applying the RSCL (Reversed Supply Chain Logistics).

The present research puts forth an overview of the CE and RSCL with the focus on the role of the applications of the information technology (IT) tools in the growth and development of the fields. As a result of the recent developments in the field of IT, such tools as RFID, IoT, Big Data etc have emerged and consequently in the last few years or so, how the concept of the 'circular economy' is getting expanded in the field of engineering and technology, as reported in the literature, is reviewed through the content-based methodology, an approach employed by (Galvao, 2018) through the present work, an effort was made to answer the following research question (RQ): 'Has the CE and RSCL nexus changed significantly under the impact of the IT tools and their applications?

The next chapter (Chapter V) presents the details pertaining to first study of the empirical investigations-based explorations undertaken in this research.

CHAPTER VI

INVESTIGATION ON CIRCULARITY ISSUES AND BT IN AUTOMOTIVE INDUSTRY

6.1 Purpose

To explore from the automotive industry stakeholders' perception viewpoints, the potential of the application of the blockchain technology (BT) with special reference to the issues of 'sustainability and circularity' in the Indian context.

6.2 Method

The research methodology employed for the present investigation was the one of the recently evolved MCDM tool called 'Best Worst Method (BWM). The details of this research methodology are same as discussed earlier in Chapter III.

6.3 Results

In the following sections, the results are summarized.

- *Weights of the yardsticks for the stakeholders' perceptions*

With the five IT experts, data were collected, BWM was applied and weights for experts were found to determine aggregate and overall weights for the criteria and sub-criteria as shown in Table 6.1. The consistency ratios pertaining to the pair comparisons were close to zero (Rezaei, 2015) showing high reliability of the results. It was found that BTP and BTA impacts on CE are the most important yardsticks. In light of the local weightings, the most important, next most important, and least important sub-criteria were respectively found to be UBTB4 (uncertainty in CE-BT as per the users; weight: 0.263), UBTA5 (use of BT in bitcoins; weight: 0.226) and DBTB5 (CE-BT requiring energy consumption and resource depletion as per the dealers; weight: 0.034). Graphically, these facts and other such features are illustrated in Fig 6.1. In terms of the global weights, the most significant, the next most significant, and the least important sub-criteria were respectively found to be UBTP5 (CE-BT requiring energy consumption & resource depletion as per the users; weight: 0.100), UBTA3 (CE-BT can support all the UNO SDGs as per the users; weight: 0.093), MBTB2 (high cost of CE-BT impact as per the auto manufacturers) and DBTB5 (CE-BT impact requiring energy consumption & resource depletion as per the dealers) both carrying the same weight of 0.008. These findings reveal two important facts. First, the local weights and global weights do not match. Second, different stakeholders have different perceptions about the importance of the same sub-criteria.

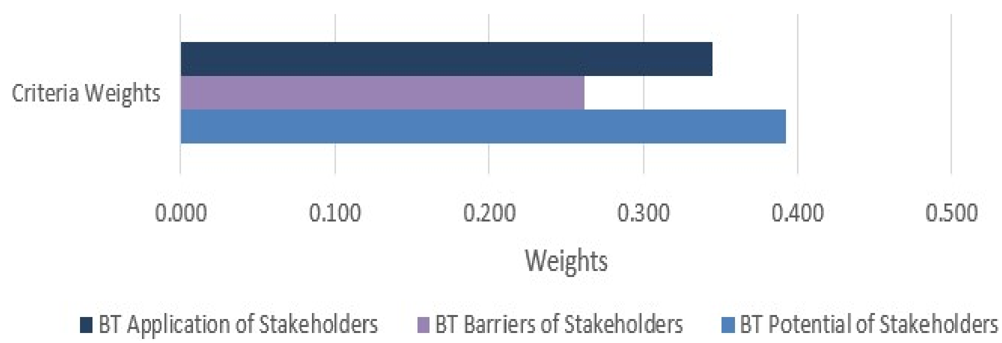


Figure 6.1 The relative importance of the primary or main criteria

For example, users' category perceived UBTP5 to be most important whereas dealers perceived the same to be least important and the reasons for this deviation are obvious from users' and dealers' business viewpoints. When analyzed in terms of different stakeholders in the auto industry, the end users revealed that the sub-criteria, 'Application of BT in bitcoins', is the most important one followed by the next one which is 'BT involves a lot of uncertainties. On the other hand, the sub-criteria, 'Larger digitization in BT requiring more energy consumption and resource depletion' emerged to be the least important perception among the users' category. Similarly, among the manufacturers' category, the sub-criteria 'BT used in manufacturing' was found to be of maximum importance while that of 'BT understanding in the industry' was found to be the least important. Among the automobile dealers, 'CE-BT impact enables ELV recovery' was found to carry the highest value while the sub-criteria 'BT requiring more energy consumption and resource depletion' was found to be the least important.

- *Stakeholders' CE-BT impact perceptions data analysis*

The survey for the data collection spanned over (a) the auto users, numbering 30, comprising of managers of top companies (b) the manufacturers of automobiles/auto parts, numbering 10 and (c) auto dealers/suppliers numbering 5, all located in the northern part of India. The questionnaire respondents filled the cells with their perception scores regarding BTP, BTB, and BTA and, also for their respective sub-criteria on a five-point Likert-type scale (1 to 5) as explained earlier.

Table 6.1. Weights for main criteria, sub-criteria, users (U), manufacturers (M), and dealers (D) and averages (Avg)

Main Criteria	*Wei-ght (Wt)*	*Sub Criteria*	*Local Wt (LW) U*	*Global Wt (GW) U*	*LW M*	*GW M*	*LW D*	*GW D*	*Avg U*	*Avg M*	*Avg D*
Potentials	0.393	BTP1	0.20	0.06	0.18	0.01	0.07	0.01	3.57	3.8	4
		BTP2	0.21	0.08	0.21	0.02	0.07	0.02	3.8	4.4	4
		BTP3	0.21	0.07	0.21	0.01	0.08	0.01	3.8	4.4	4.4
		BTP4	0.19	0.08	0.20	0.02	0.08	0.02	3.3	4.2	4.6
		BTP5	0.19	0.10	0.21	0.02	0.08	0.02	3.6	4.4	4.4
Barriers	0.262	BTB1	0.19	0.06	0.18	0.01	0.06	0.01	2.9	2.7	3.4
		BTB2	0.19	0.05	0.21	0.01	0.05	0.01	2.9	2.8	2.8
		BTB3	0.20	0.04	0.21	0.01	0.07	0.01	2.93	4	4
		BTB4	0.26	0.04	0.20	0.01	0.08	0.01	3.97	4.3	4.4
		BTB5	0.16	0.07	0.21	0.02	0.03	0.01	2.27	4	2
Applications	0.345	BTA1	0.16	0.06	0.21	0.01	0.07	0.01	2.8	4.4	4.2
		BTA2	0.20	0.07	0.22	0.02	0.08	0,015	3.53	4.6	44
		BTA3	0.21	0.09	0.21	0.02	0.07	0.02	3.73	4.4	4.2
		BTA4	0.20	0.07	0.20	0.01	0.07	0.01	3.43	4.2	4.2
		BTA5	0.23	0.06	0.18	0.01	0.06	0.01	4	3.8	3.6

The measurements of the perception scores and the weights of the yardsticks regarding CE-BT impact evaluation are given in Table 6.1. The aggregated BT impact evaluation scores of the various stakeholders with respect to their respective perceptions were computed as shown in columns 2, 4, and 6 of Table 6.3, while the ranking of each stakeholder's perception is presented in columns 3, 5, and 7. Furthermore, the overall aggregated BT evaluation of each stakeholder based on items of all perceptions and overall ranking based on this aggregated number are shown in columns 8 and 9 respectively. Assigning weights to different items (sub-criteria) and to different perceptions (main criteria) produces significant differences in the overall CE-BT impact evaluation scores for different stakeholders (Table 6.2).

Table 6.2. The overall ranking of the auto stakeholders' perception scores concerning the different criteria pertaining to BT use in the Indian auto industry. (U: Users; M: Manufacturers; D: Dealers)

Sub Criteria	*U (Score)*	*U (Rank)*	*M (Score)*	*M (Rank)*	*D (Score)*	*D (Rank)*	*Agr. All Score*	*Rank All*
BTP1	3.57	6	3.80	5	4.00	4	3.79	10
BTP2	3.80	3	4.40	2	4.00	4	4.07	6
BTP3	3.80	3	4.40	2	4.40	2	4.20	2
BTP4	3.30	9	4.20	3	4.60	1	4.03	7
BTP5	3.60	5	4.40	2	4.40	2	4.13	4
BTB1	2.90	11	2.70	7	3.40	6	3.00	12
BTB2	2.90	11	2.80	6	2.80	7	2.83	13
BTB3	2.93	10	4.00	4	4.00	4	3.64	11
BTB4	3.97	2	4.30	3	4.40	2	4.22	1
BTB5	2.27	13	4.00	4	2.00	8	2.76	14
BTA1	2.80	12	4.40	2	4.20	3	3.80	9
BTA2	3.53	7	4.60	1	4.40	2	4.18	3
BTA3	3.73	4	4.40	2	4.20	3	4.11	5
BTA4	3.43	8	4.20	3	4.20	3	3.94	8
BTA5	4.00	1	3.80	5	3.60	5	3.80	9

Finally, Table 6.3 depicts the CE-BT impact on three stakeholders in totality.

Table 6.3. CE-BT nexus impact evaluation of the perception of manufacturers (M), dealers(D), and users (U) in the Auto Industry

CE-BT Impact Features	*Questionnaire Item Nos.*	*M's Persp.*	*D's Persp.*	*U's Persp.*	*Overall Average*
CE Applications	1, 11, 12, 13, 14, 15	4.2	4.1	3.51	3.94
CE Limitations	5, 6, 8, 9	3.85	4.05	3.35	3.75
CE Cost	7, 10	3.4	2.4	2.58	2.79
Return Dimension of CE	2, 4	4.3	4.3	3.55	4.05

Reuse Dimension of CE	3	4.4	4.4	3.80	4.20

Note: Persp. Refers to 'Perspectives' in the table

The 15 variables used have been categorized as specified. These carry the questions associated with each category. It was found that all the 45 stakeholders, considered, gave maximum weight to the 'Reuse dimension of CE' while the second one is the 'CE applications' that can be best tackled by using IT tools like BT. The third and fourth columns specify the three stakeholders' perspectives individually on the CE-BT impact and all gave maximum weight to the 'Return dimension of CE'. End users gave maximum weight to this dimension when compared to the other two (6.30). Also, all the three stakeholders assess the impact of CE-BT impacts' category 'CE Applications' as the second most important while the end-users of automobiles rated this dimension as the highest when compared to the other two. These facts are illustrated through the radar diagram presented in Fig 6.2.

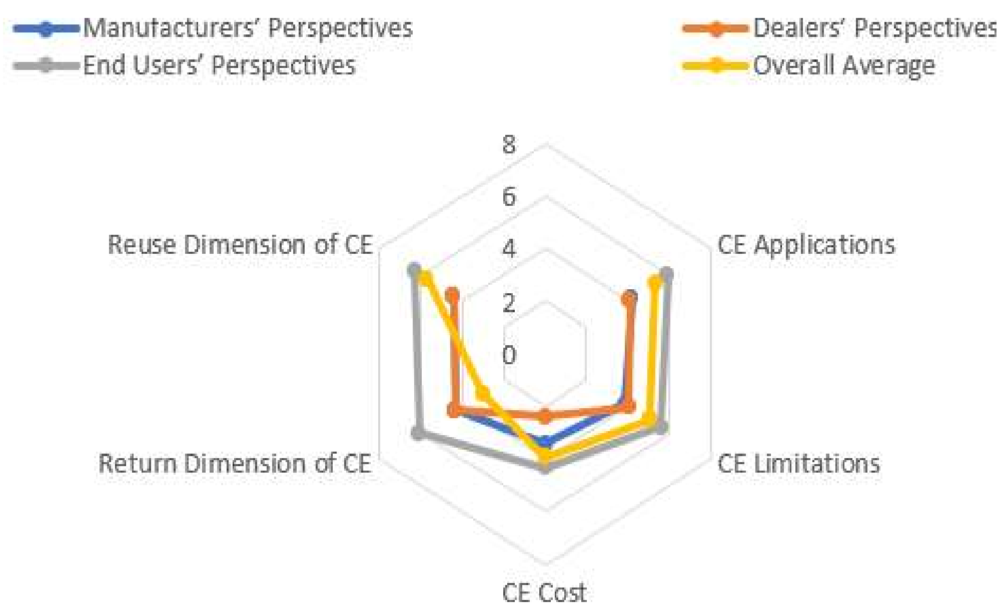


Fig 6.2 Radar diagram for the results of the study pertaining to CE-BT nexus impacts.

6.4 Discussion and conclusion

In the ever-expanding era of digitization in the industrial world, all the manufacturing functions including auto making are getting revolutionized day by day. Also, under the impact of the rapid growth of industrial production, material scarcity is also going up exponentially thereby demanding immediate need of the 'circular economy'. In light of such a scenario, the present study was planned. The study proposes a new CE-BT model that appears to be more reliable and secure than other classical models applied to CE in the auto sector. In the case study, data collected from the three stakeholders (manufacturers, dealers & end-users) on different dimensions of CE were analyzed through one of the MCDM tools called BWM. The study revealed that the structured hypotheses were found non-acceptable as all the three stakeholders considered, perceived 'Reuse dimension' and 'CE-BT applications' amongst the most crucial CE-BT impacts on the Indian auto industry. Also, the study indicated that the different criteria that were considered weighted differently as perceived by the stakeholders.

Data pertaining to CE, analyzed from Indian auto stakeholders' viewpoints through BWM, revealed the 'potential' and 'applications' as the most critical. This knowledge might be utilized by the future planners of the auto industry in knowing the intentions of the technology acceptance of the respective stakeholders keeping in mind that BT implementation has very high energy consumption costs leading to high environmental pollution costs. This endeavor could potentially mark a pioneering step in the annals of CE-BT literature, offering valuable guidance to forthcoming strategists aiming to usher in the era of digitized CE practices within the Indian automotive sector. Future researchers might address the issue of comparative perception of different stakeholders of the auto industry in terms of the CE-BT nexus impacts. In this context, the proposed operational model might prove to be helpful. Also, in the future, it would be the demand of the day to undertake similar studies for non-auto sectors, non-BT I4.0 tools, and other non-Indian parts of the world as well. Only three kinds of stakeholders were considered in the present case. In future studies, perception data might be more enriched by including a greater number of auto stakeholders. Similarly, the list of measures of CE-BT impact factors might include more numbers in future studies. Also, the modeling may further be improved in future studies by way of employing such techniques as System Dynamics Modelling (SDM).

CHAPTER VII

INVESTIGATION ON AUTOMOTIVE INDUSTRY AND INDUSTRY 4.0-CE NEXUS THROUGH THE CONSUMERS' AND MANUFACTURERS' PERSPECTIVES

7.1 Purpose

To explore the impacts of the circular economy-Industry 4.0 nexus on the Indian automotive industry from the perspectives of stakeholders of the automotive industry.

7.2 Method

The research methodology employed for the present investigation was factor analysis (FA). The details of this research methodology are same as discussed earlier in Chapter III.

7.3 Results

Pretesting the items in the research instrument revealed that for both stakeholders, the alpha value was statistically reliable enough (Table 7.1). The model was tested for both discriminant and convergent validities as shown in Tables 7.2 and 7.3. Since all the √AVE values are greater than 0.5 and since all the CVT values were found to be less than √AVE values (diagonal values), it was concluded that the constructs were validated for both convergent and discriminant validities respectively showing thereby that the measurement model is reliable and valid.

Table 7.1. Reliability Statistics & Cronbach's Alpha (α)Tests for the two stakeholders.

Stakeholder	*(α)*	*α-based on standardized items*	*Item #*	*Stakeholder*	*(α)*	*α-based on standardized items*	*Items #*
Manufacturers	0.923	0.920	20	*Auto-users*	0.915	0.919	20

Table 7.2. Convergent Validity Testing using Average Variance Extracted values.

Stake-holders	*Latent Variables*	*√AVE*	*CVT Criteria: AVE>0.5*	*Stake-holders*	*Latent Variables*	*√AVE*	*CVT Criteria: √AVE>0.5*
Manuf-acturers	RIB	0.799	Valid	*Auto-Users*	BID	0.9078	Valid
	I4T	0.687	Valid		IRID	1.006	Valid
	BRID	0.752	Valid				

Note: RIB, I4T, BRID, BID & IRID signify the following: RIB-RFID/IoT/BDA, I4T-I4.0 technologies, BRID-BDA/RFID, BID-BDA/RFID, IRID-IoT/RFID.

Table 7.3. Stakeholders' Discriminant Validity Test using Average Variance Extracted and Convergent Validities of latent variables

Latent Variables (Manufacturers)	*RIB*	*I4T*	*BRID*
RIB	√AVE=0.799	-	-
I4T	CV=0.371	√AVE=0.687	-
BRID	CV=0.365	CV=0.326	√AVE=0.752
Latent Variables (Users)	*BID*	*IRID*	
BID	√AVE=0.82	-	
IRID	CV=0.41	√AVE=1.013	

- *Factorial analyses of the stakeholders' data*

The reliability test and then EFA were conducted on the data to evaluate the factorial solutions of each construct. Firstly, the KMO measure of sampling adequacy was found to be acceptable as shown in Table 7.4. The final pattern matrix at the end of the analysis comprised of only three components with its loadings as shown in the Amos diagram in Fig 7.1. The question, "to what extent do the 3 underlying factors (RIB, I4T & BRID) account for the variance of 20 variables" was answered by the R-squared values called 'commonalities' in factor analysis. For the manufacturers, its values were more than 0.5, except T3 (representing 'a predictive maintenance scheme can be planned using real-time manufacturing data'). Therefore, T3 was eliminated from further analysis.

Table 7.4. KMO and Bartlett's tests for the stakeholders' response data.

Stakeholder	*KMO Measure of Sampling adequacy*	*Bartlett's Test of Sphericity*		
		Chi-Square (approx.)	*Degrees of freedom*	*Significant*
Manufacturers	0.757	1714.523	190	.000
End-users	0.75	3486.55	91	.000

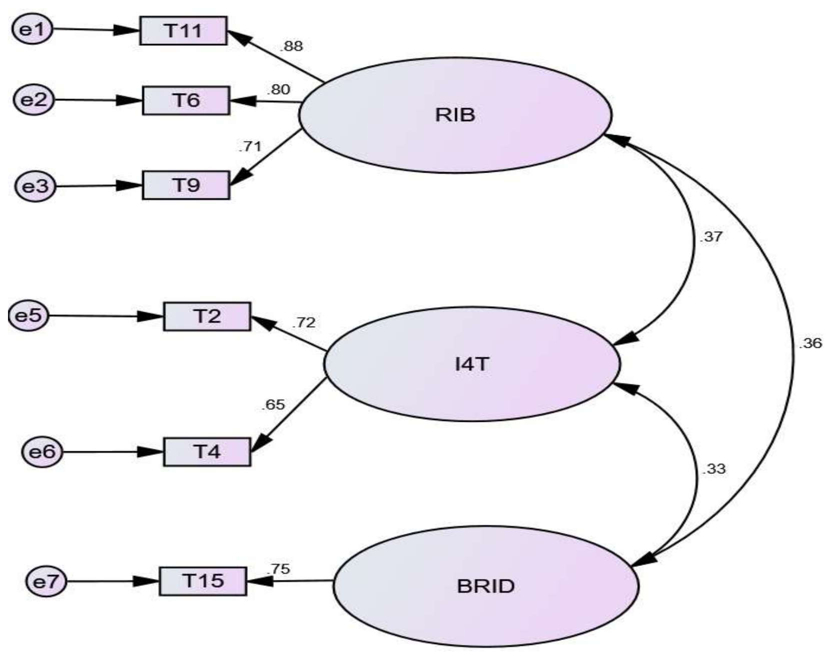


Figure 7.1. Amos Path diagram for manufacturers' data

The reason for its elimination might be traced in terms of the fact that T3 seems to have little in common with other variables. The component matrix was rotated by Varimax with Kaiser normalization resulting in component matrices, which indicated that the different components were measured by different observed variables. Next, CFA was conducted on the same data. All the variables were found to be normally distributed as the univariate skewness and kurtosis were found to be lower than 2 and 7 respectively. Fig 7.2 shows the actual model with variances depicted shown on the arrows from Amos where the four observed variables were found such that each construct represents two variables. The extent to which these four factors account for the variance of the proposed 20 variables was answered by 'communalities'. Thus, the matrix was, on the previously discussed basis, rotated by the varimax method, where the cross-loadings have been eliminated as per the norms.

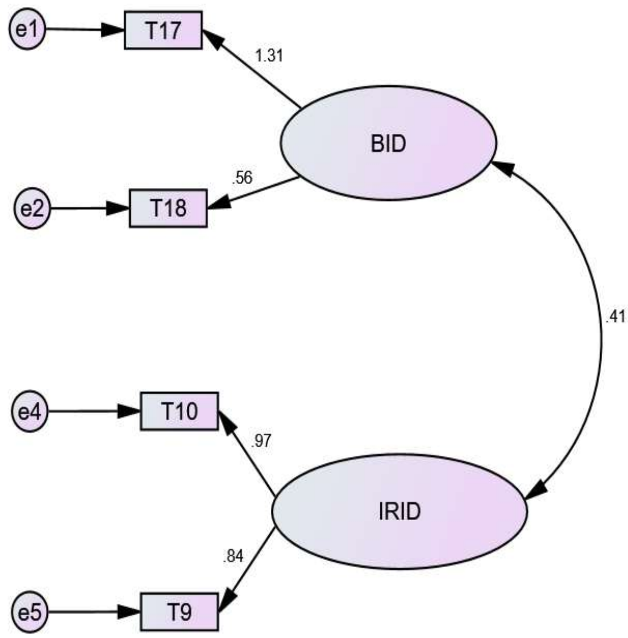


Figure 7.2 Amos Path Diagram for Automobile End Users' Data

In the model fit table obtained (Table 7.5), the CMIN (Chi-square) value found was under 5.

Table 7.5. Model Fit Summary for Stakeholders' perception data on I4.0's role in CE execution.

Index	*Threshold*	*Manufacturers*	*End Users*	*Index (I)*	*Thres-holds*	*Manufacturers*	*End Users*
Chi-Square, χ^2		7.159	3.569	*GFI*	> 0.9	0.977 (Acceptable)	0.994 (Acceptable)
df		7	1	*AGFI*	> 0.9	0.93 (Excellent)	0.94 (Excellent)
χ^2/df	≤ 5	1.023 (Good)	3.569 (Acceptable)	*RMSEA*	< 0.1	0.015 (Acceptable)	0.094 (Acceptable)
p-value	≤ 0.05	0.4125 (Non-Significant)	0.059 (Non-Significant)	*SRMR*	< 0.08	0.012 (Acceptable)	0.009 (Acceptable)

CFI	> 0	0.999 (Acceptable)	0.996 (Acceptable)				

This implied that the model fits and the two factors which load on the first component (BID) were found to be T17 and T18, while on the second component (IRID), these were T9 and T10 as shown in Fig. 9. However, the regression weight for T18 was found to be less than 0.7 (i. e., 0.56) as the standard estimate, it was still retained because otherwise, the model becomes unidentified.

7.4 Discussion and conclusion

The section that follows highlights the key findings of the current study and how they compare to previous investigations. Among the most prominent industries in any economy, the automotive industry, is considered to be the driving force. The automobile industry in India was the seventh-largest in the world in 2019, and it is now the third-largest (SIAM, 2022), earning it the title of a hub by the major players in the industry today. In light of these facts, and the ever-expanding applications of I4.0 developments in its implementation in the Indian automotive industry, it was found that studies about the role of the perspectives and perceptions of the stakeholders of the automotive industry were rarely undertaken in the past. The current research was inspired by this backdrop.

The results of this study led to models that were developed for both producers and end users in the automobile sector. The study approach used was CFA following EFA, which, as previously mentioned, offered three and two factors, respectively, for the two stakeholders that were taken into consideration. In the case of the manufacturers, there were three latent variables: 'RIB', 'I4T', and 'BRID'. Theoretically explaining, for the latent variable 'RIB', both T6 and T9 forge out new CE execution strategies in which RFID tags can monitor processes of production and consumption by using their data storage and data interaction functions. For the second latent variable, 'I4T', both the observed variables, viz., T2 and T4, come under the category of 'CE Support', as specified in Table 4. Finally, the latent variable 'BRID' has the loading of T15, which comes under the category of 'Asset Sharing'. The other two variables in the 'RIB' construct are T6 and T11 (apart from T9, already discussed). The first one of which reflects a negative question for validating whether or not the data storage and data interaction functions of active RFID tags were employed in CE execution by and large in the Indian automotive industry. RFID tags can be used to check the entire set of vehicle-related data, including such items as valid certificates pertaining to the 'Pollution Under Control', registration, insurance, etc., through the trackers. This is widely implemented in developed countries, but not in India (Piairo *et al.*, 2014). The second one (T11) relates to post-consumption products, where BDA can introduce significant changes at various stages of production to improve the delivery of automotive components, as is practically done by Knauf Industries (a large group spread across 60 countries) in some cases (Ravi, David, & Imaduddin, 2018). For the I4T construct, T2 and T4 come under the category of 'CE Support' as shown in Table 7.6.

Table 7.6. Questionnaire Question(Q)-Codes and corresponding I4.0 tools and CE constructs

I4.0 tools:	*IoT only*	*RFID only*	*BDA only*	*IoT + RFID*	*BDA + RFID*	*All Tools*
Q-codes:	T1	T5/T6/T7	T11-14/T17-20	T8/9/10	T15/T16	T2/3/4
CE-Constructs:	*Asset Sharing*	*CE Support*	*CE: Reuse*	*CE: Material-based*		*CE: Product-based*
Q-codes:	T1/T15	T2/4/6/7/17	T5/T13	T11/14/16/20		T3/8-10/18/1 9
CE-Constructs:	*Asset Sharing*	*CE Support*	*CE: Reuse*	*CE: Material-based*		*CE: Product-based*
Q-codes:	T1/T15	T2/4/6/7/17	T5/T13	T11/14/16/20		T3/8-10/18/1 9

This corroborates with the previous findings as it clearly falls under the category of significant factors (Caggia & Browning, 2020). Finally, for the construct 'BRID', in which manufacturers' category give special weightage to T15 regarding asset sharing. This helps in developing intelligence for real-time analysis of data (BCI, 2021), alerts, control of assets using dynamic edge, predictive maintenance, etc., along with automated workflows, thereby enhancing OEE (Overall Equipment Effectiveness) (Kamble, 2022). As far as the end user's data results are concerned, for the 'BID' construct, it is evident that both BDA and RFID have a direct impact on T17 and T18. For the 'IRID' construct, both IoT and RFID have a profound influence on T9 and T10. However, even though the regression weight for T18 was found to be less than 0.7 (i.e., 0.56) as a standard estimate, it was still retained because otherwise, the summary (Table 7.5) would become unidentified. The only component that connected the two stakeholders was T9, which, according to Table 7.6, falls within the category of "CE strategies based on production." For both parties, T9 is a standout variable that has been noted. An earlier study's conclusion that RFID technology can help bridge the gap between manufacturing execution systems, enterprise resource planning systems, and the shop floor lends support to this one.

In the Indian automotive industry context, Maruti Suzuki implemented an RFID-based pallet and inventory system for tracking pallets as well as managing manufactured inventory and rejects through RFID by Essen RFID company (Essen RFID Case Study, 2015). Both the observed variables, T17 and T18, are quite crucial, as the first one relates to new strategies and the second one to adaptive calibration. As the end-users were not very sure of probable new strategies in the automotive industry, most of them being technologically unaware of this industry, the responses were by and large general in nature. As for T18, the automotive end-users connived on the idea of using real-time BDA technology in adaptive calibration to save on big costs for the company. It is because the calibration data is huge-the labels can go up to 50,000 per engine control unit, one million individual values, and hundreds of vehicle variants-that new data sets are created every week for one and a half years (Backhaus, 2018). It is worth noting that a typical modern vehicle would be connected to 40 microprocessors, generating about 25 GB of cloud data per hour.

7.5 Implications, strengths and limitations of the findings

It might be noted that from the end-users' viewpoints, it is generally observed that people differ in their opinions about a product during its pre-purchasing and post-purchasing periods. In case they continue buying in the future or adopt the product for their future use also, only then might the technology be viewed as 'successful'. This is what is being referred to as 'technology acceptance', as mentioned earlier. In a recent investigation (De Graaf, Allouch, & van Dijk, 2017a), the effect of the attitudinal and behavioural values of the end-users on the acceptance of interactive technology on a long-term utilization basis was explored. Sometimes the end-users take a negative approach towards technology acceptance (De Graaf, Allouch, & van Dijk, 2017b).

Keeping these facts in view, the present study took a new initiative in developing an understanding of the two automotive stakeholders' perspectives on the I4.0-CE nexus. The main objective of this study was to identify potential I4.0-related application factors having an impact on the operational efficiency of the CE oriented automotive industry based on the perceptions of the stakeholders considered. This implies that the present findings would be helpful to the future policy planners and managers of the Indian automotive industry in evolving appropriate CE strategies under the shadow of the emerging I4.0 technologies for the digital manufacturing world of tomorrow. The findings might help automotive enterprises in benchmarking the CE strategies considered, one of which was reported in literature as the most important was 'Reuse' in the Indian context (Rizvi, Agrawal & Murtaza, 2022). In terms of the limitations of the present research, it is worth noting that the data collected for both automotive stakeholders in India was limited to only 98 manufacturers out of many more. Also, the end-users were 294 out of millions. As stated earlier, this study is based on the convenience sampling methodology, where research participants are selected on the basis of their availability (Lisa, 2008). Thus, it would not be easy to concretize the research as RMSEA emerged to be out of bounds for the manufacturers' category (Table 7.5) despite looking into MI and making new correlations between the errors of observed variables from standard residual co-variances data. This may be because AMOS, being just a software entity, remained obviously unaware of the theoretical framework of the present research, which might also have been due to the small degrees of freedom (Kenny, Kaniskan, & McCoach, 2015). Also, the present study is limited to the factors and sub-factors, and therefore, it is imperative to conduct a detailed analysis in the future. Finally, the results of this study pertain to a small populace of stakeholders in the automotive industry, that too remaining confined to the Delhi-NCR region of India. Besides, there are stakeholders in more than two categories considered in this study. Others would also have to be considered in the future to validate the present findings.

The digital advancement corridors are being traversed by the modern technology world. The rare wealth of material resources, on the other hand, is being rapidly depleted by the ever-expanding period of produced goods, harming the sustainability of the next generation. Digital tools, particularly in manufacturing like those found in the automobile sector, aid in attaining a boost in a sustainable CE environment. Therefore, the present work, based on a case study, was done to address the forthcoming issues of tomorrow's digital era and make up the research vacuum caused by the absence of any perception-based inquiry in literature, specifically in reference to the Indian automobile sector. Currently, the Indian car sector is expanding at a rapid pace, with India becoming the fifth largest auto market in 2020, up from seventh in 2019. From the perspectives of the two stakeholders in the automobile industry, the current study highlighted those crucial I4.0 components that might carry out CE initiatives in the real-life environment. The research examined the effects of I4.0 and CE on the Indian automobile sector from the viewpoints of its stakeholders, which included 294 end consumers and 98 manufacturers. Perception data, collected through a structured questionnaire, were statistically analyzed by factor analysis (exploratory and confirmatory) to get the best-fit model. Results indicated that the I4.0 technologies, such as IoT, BDA, and RFID, may have considerable influence in promulgating smart-job shops, which is the only commonality between the two stakeholders' perceptions.

Additionally, the car manufacturers thought that employing them may have a significant influence on asset analysis, waste reduction, and management of post-consumer products, whilst end users thought that I4.0 might be the ideal way to execute new strategies and those using machine tools. The two hypotheses that were formed for the current research, namely, were found to be appropriate in light of the Indian setting. This study identified the factors that were subjected to both descriptive and inferential statistical analysis based on the survey data. The identified parameters were included in the current study for two reasons: first, the variables had already been tested elsewhere by previous researchers in the I4.0-CE fields, and second, the knowledge and experience of those experts, whose opinions also served as the foundation for some of the variables, had been limited. As a result, certain factors may have avoided inclusion in the current study. It is also worth mentioning that while testing with different sets of variable values, the sensitivity of the results would need to be examined in future studies. Because this work has a restricted number of factors and sub-factors, comprehensive study will be required in future studies. It should be mentioned that both domains of knowledge, CE and the ever-expanding field of IT giving birth to novel instruments for I4.0, contribute to the enrichment of the list of linked factors with each dawn of technological advancement. As a result, the current study may not have incorporated even some prospective factors that emerged while the current work was being completed. Based on the survey data that were accessible in the literature at the time, this study identified the factors that were studied by earlier researchers using both descriptive and inferential statistical analyses. Furthermore, it appears that these elements are interconnected and have both good and negative effects on the role of IT tools in adopting CE across the Indian automobile sector. In one of the recent findings, even the coordination issues are highlighted in the context of CE (Agrawal *et al.*, 2022). As a result, it may be suggested that simulation tools be used to undertake an in-depth investigation of the disclosed connected aspects. A CLD (Causal Loop Diagram) is also advised for future study on the issue to highlight the interaction among the factors. This can be performed by conducting more interviews with top-level automotive specialists to gain a better understanding of the interrelationships among the issues mentioned. Such a study might give a comprehensive picture of the dynamic interactions between CE execution aspects in the I4.0 area in the Indian automobile sector. The literature indicated that a particular technology (like those spread over I4.0 tools) would have different levels of 'technology acceptance' by the users (in the present study, the stakeholders) at different times of the technology usage, as observed by De Graaf, Allouch & van Dijk (2017a). This implies a need to undertake studies pertaining to stakeholders' perspectives on the I4.0 technologies' acceptance on a temporal basis to have a true assessment of their perception in the future. This becomes all the more important when it is noted that 'The temporal dimension of acceptance is under-researched in technology acceptance research' (De Graaf, Allouch & van Dijk, 2017a). This exemplifies the type of characteristics that have yet to be studied and must be incorporated by future scholars in further study on the issue.

The next chapter (Chapter VIII) presents the details pertaining to third and the last study of the empirical investigations-based explorations undertaken in this research.

CHAPTER VIII

INVESTIGATION ON CIRCULAR ECONOMY-DRIVEN RETURNS AND RECOVERY MANAGEMENT IN THE INDIAN AUTOMOTIVE INDUSTRY

8.1 Purpose

To study the automotive industry stakeholders' perspectives on the return and recovery of vehicles and their parts in the Indian automotive industry within the framework of CE-based Return and Recovery Management (RRM).

8.2 Method

The research methodology employed for the present investigation was the same factor analysis (FA) as stated in the previous investigation of the CE-I4.0 related research. In addition to FA, another research tool called cluster analysis was also used in the present investigation. The details of these research methodologies are same as discussed earlier in Chapter III.

8.3 Results

The following section discusses the results of the analysis from the previous section.

- *Appropriateness of data check*

Pretesting the items in the research instrument revealed that for both stakeholders, the alpha value was statistically reliable enough (Table 8.1).

Table 8.1 Reliability statistics and Cronbach's Alpha (α) tests for two stakeholders' research instrument

Stakeholder	*(α)*	*α-based on standardized items*	*Item #*	*Stakeholder*	*(α)*	*α-based on standardized items*	*Items #*
M*anufacturers*	0.920	0.928	11	*Auto-users*	0.701	0.733	11

- *Extraction of factors*

When the stakeholders in the automotive industry provided ratings for the attributes reflected in a variety of survey questions, a correlation analysis was conducted to determine the strength of the relationships between the return types (TOR) and return influencers (IOR) categories of the variables taken into account in each of the corresponding survey questions. Such a review offers some perception on how the FA application works. The variables connected to each query were to be categorized into elements or aspects that made up several themes related to the subject. The processes required to extract the variables were spread over the EFA, PCA, and VR (Varimax Rotation). This mostly resulted in the laid-down variables being condensed into manageable components. The KMO measure (Exhibit 5) was used in EFA to determine if the data collected was adequate. Its results for the types of stakeholders that represent manufacturers and end-users were determined to be 0.608 and 0.57, respectively. Bartlett's test of sphericity was used to determine the significance of the data set; the result showed a significance level of 0.000 (Table 8.2). These test results showed that the data set was suitable for use with the FA application as a tool for data reduction.

Table 8.2. KMO and Bartlett's tests for the stakeholders' response data

Stakeholder	*KMO Measure of Sample adequacy*	*Bartlett's Test of Sphericity*		
		Chi-Square (approx.)	*df*	*Sig.*
Manufacturers	0.608	864.869	55	.000
End-users	0.57	1333.511	55	.000

- *Factor Rotation*

The rotated solution generated through the FA procedure was used to determine which variables were related to which variables. The loadings (typically represented by) are expressed in the cell entries, and only larger values of loadings (closer to 1) were to be given greater attention. Table 8.3 shows that two and four components emerged in light of the overall variation for the two types of automotive stakeholders evaluated. The presence of eigenvalues greater than 1.0 suggested that the variables were heavily loaded with these factors. The total variation explained by these variables was determined to be 68.870% for manufacturers and 71.669% for consumers, respectively. The rotational component matrix analysis indicated that in the context of the manufacturers, observed variables numbered 6, 7, and 9 are loading on factor 1, whereas observed variables numbered 1, 2, 5, and 11 are loading on factor 2. The loadings on the factors 1, 2, 3, and 4 are defined by the observed variables numbered as 8, 9, 10, and 11, and 1 & 3, 2 & 7, and 4, respectively, under the end-users' group of automotive stakeholders.

It might be observed that following Watkins (2018), those variables were eliminated that had (a) loading on more than one factor, also known as cross-loading. and (b) low loading (< 0.6) on factors. Thus, based on this analysis and theoretical modelling, the structure of the various factors associated with the two kinds of stakeholders was found as shown in Table 8.4. It was found that, according to the manufacturers' perception, the TORs as well as the IORs were important. On the other hand, from the end-users' perspective, mostly only the IORs have significance.

Table 8.3 Total variance table for the two considered auto stakeholders

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Manufacturers									
1	6.03	54.854	54.854	6.03	54.854	54.854	4.06	36.934	36.934
2	1.54	14.024	68.879	1.54	14.024	68.879	3.51	31.945	68.879
3	0.88	8.004	76.882						
4	0.73	6.597	83.479						
5	0.51	4.634	88.113						
6	0.44	3.965	92.078						
7	0.3	2.723	94.802						
8	0.22	2.002	96.804						
9	0.19	1.737	98.541						
10	0.13	1.155	99.696						
11	0.03	0.304	100						
End Users									
1	3.27	29.693	29.693	3.27	29.693	29.693	2.74	24.894	24.894
2	1.95	17.704	47.397	1.95	17.704	47.397	2.03	18.433	43.327
3	1.64	14.925	62.322	1.64	14.925	62.322	1.87	17.015	60.343
4	1.03	9.347	71.669	1.03	9.347	71.669	1.25	11.326	71.669
5	0.91	8.276	79.945						
6	0.66	5.991	85.936						
7	0.48	4.338	90.274						
8	0.46	4.149	94.423						

Component	*Initial Eigenvalues*			*Extraction Sums of Squared Loadings*			*Rotation Sums of Squared Loadings*		
	Total	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*
9	0.31	2.855	97.279						
10	0.16	1.449	98.728						
11	0.14	1.272	100						
Extraction Method: PCA									

Table 8.4 Structure of factors based on rotated component matrix for the considered stakeholders.

Auto Manufacturers		
Observed Variables	*Component*	
	1	*2*
Return program for parts/products (1)		.825
Market Returns for the company (2)		.799
Consumer Returns for the company (3)	.604	
Warranty Returns for the company (4)	.369	.586
Product Returns for the company (5)		.843
Ease of Lease Returns for the company (6)	.897	
End of Life returns for the company (7)	.890	
Return Management influenced by EPR (8)	.676	.486
Return Management influenced by WEEE (9)	.813	
Return Management influenced by hazardous substances directive (10)	.794	.305
Return program influenced by screening (11)		.786

Auto End Users				
Observed Variables	*Component*			
	1	*2*	*3*	*4*
Return program for parts/products (1)		.813		
Market Returns for the company (2)			.810	
Consumer Returns for the company (3)		.892		-.303
Warranty Returns for the company (4)				.921
Product Returns for the company (5)	.350	.396		
Ease of Lease Returns for the company (6)			.640	.303
End of Life returns for the company (7)		.433	.822	
Return Management influenced by EPR (8)	.741			-.368
Return Management influenced by WEEE (9)	.919			
Return Management influenced by hazardous substances directive (10)	.783			
Return program influenced by screening (11)	.751			

Note (s): Extraction Method: PCA, Rotation Method: Varimax with Kaiser Normalization, Rotation converged in 3 & 5 iterations for auto manufacturers and end-users respectively.

The analysis of the survey instrument (the questionnaire) and the emerging factors led to the development of Table 8.5, which presents the specific latent variables associated with each factor (two for manufacturers and four for end-users). These results would be further subjected to the CFA to obtain the final factors for best-fit modelling, as given below.

Table 8.5 Latent variables associated with factors for manufacturers and end-users in the automotive industry

Auto Manufacturers		*Auto End-Users*	
Factor #	Latent Variables	Factor #	Latent Variables
1	LSE-EOL-WEEE [TOR & IOR] [Q. Nos.: 6,7,9]	1	EPR-WEEE-HZ-SCREEN [IOR] [Q. Nos.:8, 9, 10, 11]
2	RRMP-MKT-PROD-SCREEN [TOR & IOR] [Q. Nos.: 1, 2, 5, 11]	2	RRMP-CNSMR [IOR & TOR] [Q. Nos.: 1, 3]
Note: Abbreviations for the variables are as given in Exhibit 2. [TOR: Types of Returns IOR: Influencers of Returns]		3	MKT-EOL [TOR] [Q. Nos.: 2, 7]
		4	WRRNTY [TOR] [Q. Nos.: 4]

- *CFA of the stakeholders*

Next to the EFA, the data set pertaining to the two kinds of stakeholder responses were subjected to the CFA in order to get the best-fit model for the responses of the stakeholders. The result of the IBM SPSS Amos run yielded different parameters $\chi2$ /df for manufacturers as 1.33 (< 5) and for users as 2.447 (<5) Also, the CFI for manufacturers was 0.991 (> 0.9) and for users it was 0.997 (> 0.9), while the GFI for manufacturers was 0.957 (> 0.9) and for users it was 0.997 (>0.9). These indices indicated the verification of the validity of the model. Further, whether or not the variables loaded on to the factors adequately was tested by way of the verification of convergent validity, as shown in Table 8.6. As the AVE value (which is the squired and then averaged value of the standardised regression weights for the respective factors) was larger than 0.5 for both kinds of stakeholders, it implied the desired adequacy.

Table 8.6 The testing of the convergent validity through AVE for the factors

Auto Manufacturers			*Auto End-Users*		
Factor	AVE	SQRT AVE	Factor	AVE	SQRT AVE
1	0.753	0.868	1	0.648	0.805
2	0.662	0.814	2	0.719	0.848

The AVE squire root values of 0.868 and 0.814 (for manufacturers) and 0.805 and 0.848 (for users) for the discriminant validity tests shown in Exhibit 10 turned out to be higher than the squired correlation values of 0.503 and 0.232 (for manufacturers and users, respectively). As a result, it was determined that the variables were more connected among themselves than with other factors. Thus, it can be shown that the structured construct validity is achieved based on the data presented in Tables 8.7 and 8.8.

Table 8.7 Discriminant validity testing through AVE for the factors

Auto Manufacturer			Auto End Users		
Factors	1	2	Factors	1	2
1	0.868		1	0.805	
2	0.503	0.814	2	0.232	0.848

It might be observed in Table 8.8 that the values of Cronbach's alpha are significantly large. This implies a satisfying level of internal consistency in the queries of the survey instrument. This leads to the conclusion that results are reliable.

Table 8.8 Results of the reliability testing

Auto Manufacturer			Auto End-User		
Factor #	Latent Variables	Cronbach's Alpha Value	Factor #	Latent Variables	Cronbach's Alpha Value
1	LSE-EOL-WEEE [TOR & IOR] (Q. # 6,7 & 9)	0.898	1	EPR-HZ-WEE [IOR] Q. # 8,9 &10	0.826
2	RRMP-PROD-MKT-SCREEN [TOR & IOR] (Q. # 1,2,5 ,11)	0.874	2	RRMP-CNSMR [TOR & IOR] Q.# 1 & 3	0.742

To recap, when CFA was applied for best-fit modelling, the initial variables caused the emergence of a few useful factors (two for manufacturers and four for users, as shown in Table 8.7), which were ultimately reduced to two factors for each stakeholder. Table 8.8 clearly delineates the components 1 and 2 (for each stakeholder) and the corresponding variables (question numbers). After the factor analysis, the clustering technique was carried out in the subsequent analytical phase. Thus, as shown in more detail below, factorization was done first, followed by clustering, indicating that segmentation (clustering) is based on the generic properties of the themes presented as latent variables for the pertinent components, under reference.

- *The cluster analysis*

Depending upon the strength of the components (factors) with the variables, the grouping of the variables was undertaken as shown in Table 8.8. The groups were structured through CFA on the basis of the loading values, with Factor 1 having a higher loading than Factor 2. These two respective factors 1 and 2 were found to be comprised of the variables 6, 7, 9, and, 2, 5, 11 for manufacturers and variables 8, 9, 10 and 1, 3 for users. These factors are based on the analysis of the variables, so questioning one issue in different ways would lead to a particular component or factor.

In case the cluster analysis was undertaken at this stage on the queries put before the respective stakeholders of the automotive industry, it would still be required to study which specific aspect or theme would have a higher impact on the analysis. Therefore, it was decided to perform both factor analysis and cluster analysis.

Depending on how much of the variance would be explained by the specific components or factors constituting the various thematic titles in the analysis, it may be noted that the clustering on a few factors results in the loss of richness of the original data pertaining to the perspectives of the stakeholders. It was discovered that the two acquired clusters 1 and 2 for the two different types of stakeholders in the car industry had, respectively, the structures of the variables as 6, 7, 9, and 1, 2, 5, 11 for manufacturers and as 8, 9, 10, and 1, 3 for end-users. The manufacturers' perception was spread over the two clusters 1 and 2 of 8 and 88 numbers of stakeholders, respectively, representing the 'ease of lease' and 'end-of-life' themes under the 'TOR' category plus the influence of WEEE on returns under the 'IOR' category (Cluster-1). Cluster 2, representative of the major population (88 out of 96) of manufacturers' perceptions, was spread over the RRMP as IOR, the products and market kinds of returns as TOR, and the influence of screening on returns as IOR.

On the other hand, the end-users' perception was spread over the two clusters 1 and 2 of 128 and 165 stakeholders, respectively, representing the influence of EPR (Extended Producer Responsibility), hazardous substances, and WEEE on returns under the 'TOR and IOR' categories in cluster 1 and the parts/products and consumer returns kind of themes under the 'TOR' category in cluster 2. These findings are exhibited in Tables 8.8, 8.9 and 8.10.

Table 8.9 Number of cases in each cluster

Auto Manufacturers			*Auto End-Users*		
Cluster	1	8	*Cluster*	1	129
	2	88		2	165
Valid		96	Valid		294
Missing		0	Missing		0

It was found that the manufacturers kind of auto stakeholders in cluster 1 numbered very few (8 out of 98). Moreover, their ratings for the associated variables were also very poor. On the other hand, the cluster-2 members were significantly high (88 out of 96), and their ratings also emerged to be relatively high. In terms of the thematic analysis, it was found that according to manufacturers' perspectives, among TOR, the variables market and product types of returns are important, and among IOR, the variables RRM Program and WEEE kind of influencers are important. In the case of the end-users' perception, the strengths of cluster 1 and cluster 2, which are respectively numbered 129 and 165, were not significantly different, and, therefore, the expressed perception of the entire population of the end-users appears to be valuable.

Table 8.10 Final Cluster Centres

Auto Manufacturers		*Auto End-Users*	
Variables	Cluster	Variables	Cluster

	1	2		1	2
EOL returns for the company (7)	1.88	4.48	End of Life returns for the company (7)	2.83	3.44
Ease of Lease (LEAS) Returns for the company (6)	2	4.41	Ease of Lease Returns for the company (6)	3.18	3.09
Return Management influenced by EPR (8)	3	4.45	Warranty Returns for the company (4)	3.34	3.04
Return Management influenced by WEEE (9)	3	4.48	Market Returns for the company (2)	3.4	3.38
Return Management influenced by hazardous substances directive (10)	3	4.5	Return program for parts/products (1)	3.5	3.15
Market Returns for the company (2)	4	4.45	Return program influenced by screening (11)	3.55	3.12
Product Returns for the company (5)	4	4.45	Consumer Returns for the company (3)	3.57	3.12
Return program for parts/products (1)	4.13	4.43	Product Returns for the company (5)	3.69	3.24
Consumer Returns for the company (3)	4.13	4.55	Return Management influenced by hazardous substances directive (10)	4.18	3.22
Warranty Returns for the company (4)	4.13	4.45	Return Management influenced by WEEE (9)	4.29	3.24
Return program influenced by screening (11)	4.13	4.39	Return Management influenced by EPR (8)	4.41	3.25

Accordingly, the results for them revealed that among the TOR, only the variable 'consumer returns' was important, and among the IOR, the variables RRM Program, hazardous substances directives (HZ), WEEE, and the EPR as influencers emerged to be significantly important. Thus, the common influencers among the considered two types of stakeholders emerged to be the RRM Program and WEEE, whereas under the TOR variables, none appeared to be common among them.

8.4 Discussion and conclusion

The present research explored the perceptions of the Indian automotive industry stakeholders about the RRM process in terms of their opinions regarding TOR, which included such kinds as market returns, consumer returns, warranty returns, product returns, ease of lease returns, and end-of-life returns. In addition, the exploration also included the other variable category, IOR, spanning such influencers as 'RRM Program', 'EPR', 'WEEE', 'hazardous substances directives, and 'screening'. The tools employed for data analysis were FA (spanning EFA and CFA) and cluster analysis, as detailed earlier. It was noted that since the last two decades or so, the world has seen a continual enhancement in the awakening of the need to protect the environment and make the future human race more sustainable. On the one hand, this kind of concern needs to envelop business persons (Islam *et al*., 2021), and on the other, this awakening needs to be generated in individuals as well (Ofori and Mensah, 2021). On individual levels, in general, it was observed that in disposing of the things used by end-users, such feelings need to be reflected in their behaviour as a 'habit (Ahmad *et al*., 2020). The strategic role of RRM in terms of economic benefits was also emphasised in the literature (e.g., de Araújo *et al*., 2018). Virmani *et al*. (2021) studied the automotive industry to demarcate the barriers that hinder their manufacturing practises from becoming sustainable. In another piece of research, Kumar *et al*. (2021a) conducted a study on sustainable lean manufacturing (SLM) involving enhanced control over adverse environmental effects and alleviation of the level of waste of natural resources. In this research, the problem of RRM was viewed within the framework of the CE because it becomes highly critical in light of a recent study by Trang and Li (2022). They observed that on one hand, EoL vehicles are exceedingly valuable from a recycling viewpoint, while on the other hand, if not managed and handled appropriately, these might be very damaging from an environmental health viewpoint. In light of such observations, the present study explored how stakeholders in the auto industry perceived different facets of the RRM process in India. It should be highlighted that a study like this one is innovative and original in the sense that it closes research gaps by, for example, showing that consumers of the items are not currently "satisfied" in terms of the necessary "disposal habit". Second, according to Shan *et al*., (2021), despite recent increases in environmental consciousness, this mentality could not be instilled as a 'habit' among end-users in terms of returning old items. In this context, it might be noted that RRM is becoming more important not only among researchers but also among supply-chain practitioners (de Araújo *et al*., 2018). How are the RRM-related components seen by the "TOR" and "IOR" essential aspects of the automotive industry's manufacturers and end users? comprised the main subject of the present investigation. The findings of the current study about the perspectives of the various stakeholders in the Indian automotive sector should be taken into consideration while designing future policies and realigning the RRM, not only in India but also in other growing nations like India. As stated under the results' context, the manufacturers' category of stakeholders believed that among the various types of returns in the auto industry taken into account in this study, the TOR spanned over market and product TOR and the IOR spanned over RRM Programme and WEEE influencers. The end-users' group, on the other hand, showed that only "consumer returns" were significant under the TOR dimension of return, and that the IOR variables RRM Programme, hazardous substances directives (HZ), WEEE, and the EPR were major influencers. In the contemporary literature, it is becoming more important to examine how corporate organisations, manufacturers, and end users understand the RRM from sustainability and economic perspectives. Future expectations call for a very lucrative and competitively advantageous automotive sector for all relevant stakeholders thanks to intelligent RRM management based on the cutting-edge IT solutions covered by I4.0. Such evidence is also contained in many studies undertaken in the past (e.g., de Araújo *et al*., 2018). The cluster analysis yielded valuable results, indicating varieties of variables pertaining to different facets of RRM to be treated at par by the policy planners and the field practitioners in consultation with each other. Perception based RRM studies are hardly available in the literature, particularly in the context of the Indian automotive industry. Nevertheless, Zailani *et al*. (2017) conducted a comprehensive study on the Malaysian auto industry, focusing on the analysis of RRM status reporting. The study delved deeply into the subject matter, providing valuable insights.

Generally, it is evident that individuals hold diverse opinions on various matters. It is not reasonable to assume that participants in the car business won't exhibit this sort of behaviour as well. Moreover, it is commonly found that when the same commodity is purchased and repurchased by the end-users, the scientific world names this phenomenon ‘technology acceptance’ as observed by (De Graaf *et al*., 2017a). They also discussed how consumers' refusal to continuously buy the same product might have a detrimental impact on how technology is perceived (De Graaf *et al*., 2017b). So, whether they are in Malaysia or other countries like India, where this sort of new project of perception-based research on RRM has to be studied, such studies would prove to be of tremendous benefit for future policy planners of RRM in the car sector. This means that research on consumer perceptions of used goods will have a big influence on RRM. According to certain observations (e.g., Janakiraman & Ordóez, 2011), a "lenient return policy" may also be viewed as a "customer convenience".

Recently, several initiatives have been put into place in the framework of environmental protection and RRM by various governments and experts throughout the world, such as WEEE and RoHS (Restriction of Hazardous Substances). Under the impact of such initiatives, manufacturers in the automotive industry, in particular, have awakened to the elimination of automotive products, resulting in minimising landfill problems. China has been creating this kind of awakening among auto producers for a long time with higher "disposal fees" for manufacturers (Lai and Wong, 2012). As the globe looks to be becoming increasingly concerned about environmental pollution, which eventually influences 'climate change,' the work by Gahlot *et al*. (2023) is noteworthy. They observed that in the context of the Indian automotive industry, there was a ‘significant’ research gap in the identification of the barriers pertaining to GSCM (Green Supply Chain Management) and claimed that their study has taken an initiative in this direction. Karuppiah *et al*. (2022) also identify GSCM as one of three technical requirements that may enhance the industry's technical capability. among the considered two types of stakeholders emerged to be the RRM Program and WEEE, whereas under the TOR variables, none appeared to be common among them.

The next chapter (Chapter IX) presents the summarised version of the five investigations pertaining to the literature-based and the empirical investigations-based explorations undertaken in the present research along with social and managerial impacts and the research limitations.

CHAPTER IX

SUMMARY OF THE INVESTIGATIONS, CONCLUSIONS, PURSUING CE IN A COMPANY, FUTURE SCOPE OF RESEARCH, THE RESEARCH LIMITATIONS AND ITS SOCIAL IMPACTS

9.1 Summary of investigations

Corresponding to the five objectives laid down for the present research work, there were five explorations which were detailed in the last chapters of this thesis and the same are presented in summarized forms as follows:

9.1.1 Summary of research on circular economy as enabler for our environment in auto arena

Today's technological world is passing through an era which demands not only 'conservation' but also 'circulation' of resources. In the days ahead, products like an automobile that the manufacturers would have to take care of over the entire tenure of its life cycle, might require more collaborative and supportive relationship with its customers than that being practiced today. The future auto product design has to be such that the products/parts might get subjected to different components of the CE depending on the needs of the customers. In the context of the CE-auto nexus, recent developments in the field of IT tools like IoT, Big Data etc. appear to be highly promising in the days ahead. The fourth industrial revolution (I4.0) is anticipated to encounter CE challenges pretty successfully (Bressanelli *et al.*, 2018). It was found that even though huge quanta of scientific work are available today, there exists a promising growth potential for future research in the related fields (Tseng *et al.*, 2018). As mentioned above, when CE-IT nexus-based applications were reviewed it appeared that CE applications are yet passing through the infancy stages (Jain, 2017).

In the scientific handling of the ELV affairs in developing countries like Malaysia and India, there are many challenges such as development of recovery databases, particularly when a huge increase in vehicular population is observed

(Zainul, 2018; Petronijevic, 2020). The concept of the residual value of a product and its parts when it reaches its EOL was discussed by Liu *et al* (2018) and its evaluation in terms of the value recovery can be challenging as was demonstrated by Grdic *et al* (2020). Also, there are big challenges in the auto sector so far as the economic sustainability (Xin, 2016) is concerned. However, it has been generally agreed that a holistic approach on sustainability should be undertaken (Morgadinho *et al.*, 2015; Stolka *et al.*, 2019). Moreover, earlier researches pertained to only scientific works and did not address the industry-based issues (Engert *et al.*, 2016a) and many researchers called for further research on the topic (Engert *et al.*, 2016b), especially when it comes to managing Green House Gas (GHG) emissions which is still a substantial challenge for the countries like Saudi Arabia (Rahman *et al.*, 2017).

9.1.2 Summary of research on circular economy under the impact of IT tools

The investigations on the impact of IT tools on CE in the automotive industry revealed that with the days passing by, the possibility of more and more material consumption is also going up. It is expected that at the global level, there would be eight-fold increase in material consumption by the end of 2050 (EC Report 2019).

The future-product that a company has to manage over its entire life cycle might require more collaboration with its customers' population than is customary today. Product design has to be such that its products can be refurbished, reused, repaired, and recycled. The firms too need processes and systems which come to the rescue of customers when the products wear out, become obsolete, or fail. Product development affects everybody profoundly in the value chain, be it any internal entity like marketing, sales etc. or external elements like suppliers, freight carriers, distributors, and retailers. All of such concerned parties must have a say in the process of the product development. There are varieties of challenges in CE applications and digital technologies can overcome these challenges successfully (Bressanelli *et al.*, 2018). It was found by Tseng *et al* (2018) that 'despite a massive volume of scientific work in these areas (e.g., separate queries in Scopus using Industry 4.0 and Circular Economy as key words yield 4060 and 2452 published documents, respectively), there is plenty of growth potential for ground breaking research in the nexus of these'. In this context, the newly developed conceptual CE business model Lewandowski (2016) might be revisited in real-life CE implementation framework. Future research might also focus on those dimensions which appear to have been neglected by the previous researchers working on CE, particularly from the consumer perspective point of view.

It has been observed by Suárez-Eiroa *et al.* (2019) that the literature available on the CE is still scarcer and 'both conceptual discussions and the development of practical strategies for its implementation are still emerging'. From quantitative analysis viewpoint future researches might be based on the application of environmental scanning with the AHP/affinity diagram employed as a tool for targeting at strategic reversed logistics flexibility-based modelling, equipped with the capability of handling uncertainty, so as to evolve some theoretical framework that provides strategic capability of the future manufacturing entities. This might enable the upcoming generation of enterprises to cope with the uncertain business environment of tomorrow. Finally, in the context of the CE applications, Davenport and Beans (2017) claimed that data-driven culture often prevents the adoption of Big Data applications whereas Mieras (2016), emphasized that CE is hard to apply and offers a big challenge, particularly in light of such barriers as technological, social, customer-related, financial and economic, managerial, policy and regulatory and performance indicators related as identified by (Galvao *et al* 2018). However, Hossfeld (2017) observed that in future manufacturing, Big Data analytics would be a 'key success factor'. It has been suggested that initiatives should be taken only on the step-by-step basis for its genuine success (IFU, 2018).

9.1.3 Summary of research on Investigation on circularity issues and BT in automotive industry

The blockchain technology related research revealed that in the ever-expanding era of digitization in the industrial world, all the manufacturing functions including automotive making are getting revolutionized day by day. Also, under the impact of the rapid growth of industrial production, material scarcity is also going up exponentially thereby demanding immediate need of the 'circular economy'. In light of such a scenario, the present study was planned. Also, the study indicated that the different criteria that were considered weighted differently as perceived by the stakeholders. The data pertaining to CE, analyzed from Indian auto stakeholders' viewpoints through BWM, revealed the 'potential' and 'applications' as the most critical. This information could help future planners in the car industry understand how stakeholders feel about accepting new technology. It's important to remember that implementing new technology can use a lot of energy and create pollution. This might be one of the first times someone has written about this in literature about Circular Economy and Blockchain Technology (CE-BT). It could be useful for planners who want to introduce digital CE in Indian automotive industry. In the future, researchers might look at how different people involved in the car industry see the impact of CE-BT.

9.1.4 Summary of research on Investigation on automotive industry and industry 4.0-CE nexus through the consumers' and manufacturers' perspectives

The research pertaining to the CE-I4.0 nexus in automotive industry indicated that the digital advancement corridors are being traversed by the modern technology world. The rare wealth of material resources, on the other hand, is being rapidly depleted by the ever-expanding period of produced goods, harming the sustainability of the next generation. The research examined the effects of I4.0 and CE on the Indian automobile sector from the viewpoints of its stakeholders, which included 294 end consumers and 98 manufacturers. Perception data, collected through a structured questionnaire, were statistically analyzed by factor analysis (exploratory and confirmatory) to get the best-fit model. Additionally, the car manufacturers thought that employing them may have a significant influence on asset analysis, waste reduction, and management of post-consumer products, whilst end users thought that I4.0 might be the ideal way to execute new strategies and those using machine tools. The two hypotheses that were formed for the current research, were found to be appropriate in light of the Indian setting. Because this work has a restricted number of factors and sub-factors, comprehensive study will be required in future studies. It should be mentioned that both domains of knowledge, CE and the ever-expanding field of IT giving birth to novel instruments for I4.0, contribute to the enrichment of the list of linked factors with each dawn of technological advancement. As a result, the current study may not have incorporated even some prospective factors that emerged while the current work was being completed. Based on the survey data that were accessible in the literature at the time, this study identified the factors that were studied by earlier researchers using both descriptive and inferential statistical analyses. Furthermore, it appears that these elements are interconnected and have both good and negative effects on the role of IT tools in adopting CE across the Indian automobile sector. In one of the recent findings, even the coordination issues are highlighted in the context of CE (Agrawal *et al.*, 2022). As a result, it may be suggested that simulation tools be used to undertake an in-depth investigation of the disclosed connected aspects. A CLD (Causal Loop Diagram) is also advised for future study on the issue to highlight the interaction among the factors. This can be performed by conducting more interviews with top-level automotive specialists to gain a better understanding of the interrelationships among the issues mentioned. Such a study might give a comprehensive picture of the dynamic interactions between CE execution aspects in the I4.0 area in the Indian automobile sector. The literature indicated that a particular technology (like those spread over I4.0 tools) would have different levels of 'technology acceptance' by the users (in the present study, the stakeholders) at different times of the technology usage, as observed by De Graaf, Allouch & van Dijk (2017a). This implies a need to undertake studies pertaining to stakeholders' perspectives on the I4.0 technologies' acceptance on a temporal basis to have a true assessment of their perception in the future. This becomes all the more important when it is noted that 'The temporal dimension of acceptance is under-researched in technology acceptance research' (De Graaf, Allouch & van Dijk, 2017a). This exemplifies the type of characteristics that have yet to be studied and must be incorporated by future scholars in their further studies on the issue.

9.1.5 Summary of research on Investigation on Circular Economy-Driven Returns and Recovery Management in the Indian Automotive Industry

The research on RRM system in the automotive industry revealed that the number of returns and recovery of the cars is providing new issues for the researchers of the future as the automotive sector, both at the global and at the national level, is expanding day by day, particularly under the recent advancements of I4.0-based technologies. Around a decade ago or so, there was a sense that, despite its strategic importance, the 'returns' of customers remained unexplored (Bonifield *et al.*, 2010), and perhaps the situation remains more or less the same today, indicating an immediate need to undertake current type of research in the days ahead. Such investigations are necessary, especially because all product manufacturers want to keep their clients for the long run. Fernando, Shaharudin, and Abideen (2023) proposed a consumer-centric approach for implementing reverse logistics in the context of sustainable resource utilization. Examining how end-users and manufacturers interpret "TOR" and "IOR" contributes not only to future planning in the auto industry but also to environmental protection, fostering a more sustainable future. The present study delved into the realm of the Indian automobile sector, specifically directing its attention towards end-users and manufacturers as key stakeholders. However, future scholars should aspire to embrace a broader scope by encompassing not only diverse regions of India but also the expansive global automotive industry. Furthermore, it would be advantageous to incorporate other categories of stakeholders within the sample. By expanding the participant pool, a more profound comprehension of individuals' perceptions regarding the RRM system can be attained, leading to a holistic understanding of its dynamics. Moreover, it is worth noting that the current analysis explored only a limited array of return types. Future investigations exploring the perspectives of auto industry stakeholders should endeavour to explore potential types of returns that remain undiscovered but have been elucidated in the literature. It is crucial to underscore that when end-users perceive a disconnect between the items they employ and their expectations, the process of returns ensues. In such instances, RRM data can furnish invaluable insights for ergonomics specialists. This, in turn, may pave the way for the development of ergonomically designed products, ultimately reducing the occurrence of returns within the automotive sector.

Further, the above stated facts are summarised in the form of a flowchart as given in Fig 9.1.

9.2 Concluding Words

As stated earlier, out of the five explorations the two were based on the literature search while the remaining three were in the form of empirical studies. Accordingly, the conclusions were drawn from the five studies as presented below:

9.2.1 Conclusions pertaining to the study on circular economy as an enabler for our environment in auto arena

In terms of the major findings of the literature-reviewed on circular economy as enabler for our environment in auto arena it is concluded that even in case of automobiles, only developed nations have taken steps in implementing the CE applications. Thus, underdeveloped countries like India have to initiate ‘remanufacturing’ particularly in the field of automobiles and two-wheelers. The literature search indicated that almost no or hardly few studies on CE based applications pertaining to the two-wheelers are available at the global/national level. On the other hand, it is observed that India and China are the two giant leaders in two wheelers’ industry in the world. With reference to Indian two-wheeler industry, there is a dire and immediate need to investigate the scope of the circular economy applications, remanufacturing industrial initiatives, and IT tools application in the field of the design and development of the products and processes in the auto industry. Also, ELV based studies are needed to be undertaken both by the academia as well as the industrial houses, in a more organized manner particularly in developing parts of the world. It is reported that BS-8001:2017 is the first standard designed for the CE, implying thereby the need to develop such a standard specifically for the auto sector with the shortcomings of the present standard removed. Finally, it is worth noting that, today and in the days ahead, digital technology involving IT tools and their applications find an emerging era of usability, particularly, in the CE-based “remanufacturing industry”.

9.2.2 Conclusions pertaining to circular economy under the impact of IT tools

In terms of the major findings of the literature-reviewed on circular economy under the impact of IT tools it is concluded that today’s, ongoing efforts by the researchers in the fields of CE-RSCL-DT nexus, as reported in literature, indicate an immediate urgency for a more concerted intervention by the future investigators in their respective areas of works, particularly, when it is noted that ‘the potential for digital intelligence to enable a regenerative economy is promising’ (Moreno & Charnley 2016). Conservation of energy has always been an everlasting demand in the field of engineering and technology. Today the scenario has got broadened. It is not only the energy travelling on the path of depletion but the whole world of resources needed in the field of manufacturing is demanding not only for ‘conservation’ but also for ‘circulation’. Therefore, as a part of the CE strategy the need of the day is to revisit the classical process of product development. Recent developments in the field of IT tools do provide a good support to the emerging dimensions of the CE-RSCL under the impacts of the applications of the upcoming IT tools like RFID, IoT and Big Data etc. It appears that the fourth industrial revolution that highlighted the IT tools like Big Data, 3D Printing, IoT, and Analytics etc. The study proposes a new CE-BT model that appears to be more reliable and secure than other classical models applied to CE in the auto sector.

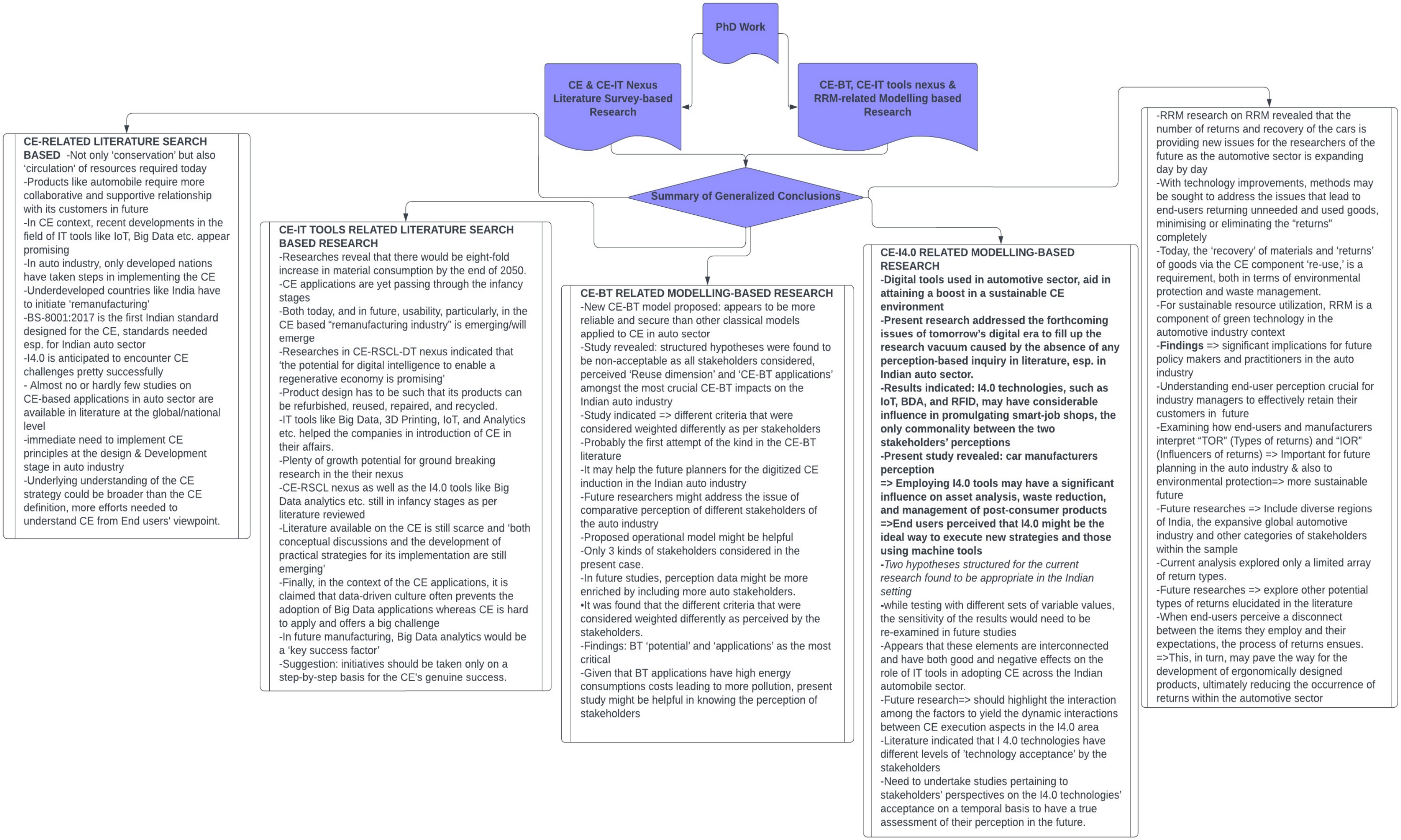


Figure 9.1 Summarised Flowchart of PhD Work

In the case study, data collected from the three stakeholders (manufacturers, dealers & end-users) on different dimensions of CE were analyzed through one of the MCDM tools called BWM. The study revealed that the structured hypotheses were found to be non-acceptable as all the three stakeholders considered, perceived 'Reuse dimension' and 'CE-BT applications' amongst the most crucial CEBT impacts on the Indian auto industry. Other matter-contents indicated the infancy stages for CE-RSCL nexus as well as the emerging IT tools like BDA etc. applications (Jain et al 2017) implying thereby in immense scope for their development and growth in the days ahead. In this context, as acknowledged by the authors also, perhaps underlying understanding of the CE strategy could be broader than the definition presented in the literature. This might lead to possibly making of more efforts in future to explore some more dimensions in CE understandings. It might be observed that revisiting CE definition by the future researchers might be a contribution to the scholarly CE community and this kind of definition might ideally serve as a conceptual foundation for future work on the topic.

9.2.3 Conclusions pertaining to circularity issues and BT in automotive industry

In terms of the major findings of the literature-reviewed on circularity issues and BT in automotive industry it is concluded that present study proposes a new CE-BT model that appears to be more reliable and secure than other classical models applied to CE in the auto sector. In the case study, data collected from the three stakeholders (manufacturers, dealers & end-users) on different dimensions of CE were analyzed through one of the MCDM tools called BWM. The study revealed that the structured hypotheses were found non-acceptable as all the three stakeholders 106 considered, perceived 'Reuse dimension' and 'CE-BT applications' amongst the most crucial CE-BT impacts on the Indian auto industry. The proposed model might be helpful in this context. Also, it will be important to study other industries, different technology tools, and parts of the world outside India. Right now, this study only looked at three kinds of stakeholders in the car industry. Future studies might include more stakeholders to get a better understanding. They might also look at more factors that affect CE-BT. Using techniques like System Dynamics Modelling (SDM) could improve the modelling in future studies.

9.2.4 Conclusions pertaining to automotive industry and Industry 4.0-CE nexus through the consumers' and manufacturers' perspectives

In terms of the major findings of the literature-reviewed on automotive industry and industry 4.0-CE nexus through the consumers' and manufacturers' perspectives it is concluded that digital tools, particularly in manufacturing like those found in the automotive sector, aid in attaining a boost in a sustainable CE environment. Therefore, the present work, based on a case study, was done to address the forthcoming issues of tomorrow's digital era and make up the research vacuum caused by the absence of any perception-based inquiry in literature, specifically in reference to the Indian automobile sector. Currently, the Indian car sector is expanding at a rapid pace, with India becoming the fifth largest auto market in 2020, up from seventh in 2019. From the perspectives of the two stakeholders in the automobile industry, the current study highlighted those crucial I4.0 components that might carry out CE initiatives in the real-life environment. This study identified the factors that were subjected to both descriptive and inferential statistical analysis based on the survey data. Results indicated that the I4.0 technologies, such as IoT, BDA, and RFID, may have considerable influence in promulgating smart-job shops, which is the only commonality between the two stakeholders' perceptions. The identified parameters were included in the current study for two reasons: first, the variables had already been tested elsewhere by previous researchers in the I4.0-CE fields, and second, the knowledge and experience of those experts, whose opinions also served as the foundation for some of the variables, had been limited. As a result, certain factors may have avoided inclusion in the current study. It is also worth mentioning that while testing with different sets of variable values, the sensitivity of the results would need to be examined in future studies.

9.2.5 Conclusions pertaining to Circular Economy-Driven Returns and Recovery Management (RRM) in the Indian Automotive Industry

In terms of the major findings of the literature-reviewed on Circular Economy-Driven Returns and Recovery Management in the Indian Automotive Industry it is concluded that with technology improvements, methods and solutions may be sought to address the issues that lead to end-users returning unneeded and used goods, minimizing or eliminating the "returns" completely. In contemporary terms, it is recognized that RRM is a component of green technology, as noted by Zailani et al. (2017) in the automotive industry context. Today, the 'recovery' of materials and 'returns' of goods via the CE component 're-use,' have arisen as a pressing requirement, both in terms of environmental protection and waste management. The findings of this research have significant implications for future policy makers and practitioners in the auto industry. The understanding of end-user perception, as explored in this study, will offer valuable insights for industry managers to effectively retain their customers in the future.

9.3 Pursuing CE in a manufacturing company

How to organize CE in a company so that it functions under the requirements of the CE environment can be illustrated as follows:

Consider the case of a furniture company that specializes in creating eco-friendly and durable products. They employ sustainable design strategies pertaining to materials. They source sustainably harvested wood and use recycled materials in their furniture production); Durability (The furniture is designed to withstand wear and tear, reducing the need for frequent replacements); Modularity (The pieces are designed to be modular, allowing for easy assembly, disassembly, and customization); End-of-life Solutions (The company offers a take-back program for recycling or re purposing furniture at the end of its life.)

By incorporating these sustainable design principles, the company minimizes waste, conserves resources, and meets the growing demand for environmentally conscious products. The company needs to include following features in its sustainable design of the furniture items: Design for Longevity(Creating products that are durable, repairable, and upgradable to extend their lifespan);Material Circularity(Using materials that are renewable, recyclable, or biodegradable to ensure they can be continuously cycled in the economy);Resource Efficiency(Optimizing resource use throughout the product lifecycle, including raw material extraction, manufacturing processes, and end-of-life treatment); and Collaborative Approaches(Encouraging collaboration among stakeholders to maximize resource productivity, share knowledge, and create closed-loop systems). Product design plays a crucial role in enabling a circular economy by integrating circular principles into product design, material selection, and business models. By considering the entire product life cycle, designers can identify opportunities for waste reduction, design for disassembly and recycling, and create products that facilitate reuse and repair. Product design also drives innovation in sustainable materials, production methods, and closed-loop supply chains, enabling the transition to a circular economy. Adopting circular design approaches offers benefits like Waste Reduction, Resource Conservation, Cost Savings, Enhanced Customer Value,and Environmental Stewardship. By embracing circular design principles, designers can drive sustainable innovation, create value for businesses and customers, and contribute to the transition towards a circular economy. To design for a circular economy, several key strategies which could be employed include Materials Selection: Explore sustainable and recyclable materials options, such as bio-based plastics or recycled metals. Consider the life cycle impact of materials, including extraction, production, use, and disposal. Promote the use of renewable and bio-based materials to reduce reliance on finite resources. Durability and Longevity: Design products that are built to last, using high-quality materials and robust construction methods. Consider the expected lifespan of the product and design for durability accordingly. Encourage customers to invest in long-lasting products by highlighting the value and benefits they provide. Modularity and Adaptability: Embrace modular design principles to allow for easy disassembly and reconfiguration. Design products that can adapt to changing needs or technological advancements. Enable component-level upgrades and replacements to extend the product's lifespan and Repair, Reuse, and Recycling: Incorporate design features that facilitate easy repair, reducing the likelihood of product abandonment. Explore opportunities for product reuse or repurposing, such as designing for second-life applications. Ensure products are designed with recyclability in mind, minimizing the complexity of the recycling process.

To truly drive sustainable practices, collaboration and integration of sustainable principles throughout the supply chain are essential. Engaging Stakeholders: Involve stakeholders, including employees, customers, and communities, in the design process. Seek feedback and insights to ensure that sustainability considerations are adequately addressed. Collaboration with Suppliers and Manufacturers: Work closely with suppliers and manufacturers to establish sustainability criteria and standards. Encourage suppliers to adopt sustainable practices in their operations and supply chain and Closed-Loop Supply Chains: Establish closed-loop supply chains that enable the recovery and reuse of materials. Explore partnerships with recycling facilities or service providers to close the loop effectively.

To cite a case of the successful CE-based company it might be noted that Interface Inc, a global leader in commercial flooring, embraced sustainable design principles by introducing modular carpet tiles. By adopting a "take-back" program, the company offers customers the option to return used carpet tiles for recycling and reprocessing into new products. This initiative significantly reduces waste and conserves resources. Through their ReEntry program, Interface has successfully closed the loop on carpet production and set an example for the industry. Another success story is the case of Patagonia. The outdoor apparel company Patagonia implemented its Worn Wear program, promoting the repair and reuse of clothing. Recognizing the environmental impact of textile waste, Patagonia established repair centres where customers can have their worn clothing items repaired, extending their lifespan. The company also provides resources and guides for customers to perform repairs themselves. By encouraging reuse and reducing the demand for new products, Patagonia exemplifies sustainable practices in the fashion industry'

The above discussed examples amply illustrate the tangible benefits and positive impact of sustainable design in real-world settings. They demonstrate that by integrating circular economy principles into product design and encouraging consumer participation, businesses can contribute to waste reduction, resource conservation, and a more sustainable future.

9.4 Future scope of research

Based on the literature search and different empirical explorations undertaken in the present research work, it was found that varieties of research gaps emerged. Also, the limitations of the time and other resources presented obstacles in furtherance of more extensive empirical work and that led to report following directions of future research on the yet unexplored areas of the related topics:

Today's ongoing efforts by the researchers in the fields of CE-RSCL-DT nexus indicated that 'the potential for digital intelligence to enable a regenerative economy is promising'. Present review of the related matter-contents indicated the infancy stages for CE-RSCL nexus as well as the emerging IT tools like Big Data analytics etc. applications implying thereby in immense scope for their development and growth in the days ahead.

• So far as the challenges are concerned, it is worth noting that more and more precious and valuable natural resources are getting scarcer day by day. From the material resource viewpoint, predictions indicate an eight-fold enhancement in its consumption by the year 2050. Research works in the field of CE-IT nexus is highly promising so far as the regenerative nature of the economy is concerned.

• The present research could be the first attempt of its like in the CE-BT literature, and it could be beneficial to those who aim to develop the digital CE induction in the Indian car sector in the future. Future researchers might address the issue of comparative perception of different stakeholders of the auto industry in terms of the CE-BT nexus impacts. In this context, the proposed operational model might prove to be helpful. Based on the survey data that were accessible in the literature at the time, this study identified the factors that were studied by the earlier researchers using both the descriptive and the inferential statistical analyses. Furthermore, it appears that these elements are interconnected and have both good and negative effects on the role of IT tools in adopting CE across the Indian automobile sector. In one of the recent findings, even the coordination issues are highlighted in the context of CE (Agrawal *et al.*, 2022). As a result, it may be suggested that simulation tools be used to undertake an in-depth investigation of the disclosed connected aspects. A CLD (Causal Loop

Diagram) is also advised for future study on the issue to highlight the interaction among the factors. • Electric vehicle market needs to be paid more attention by the future manufacturers of the auto sector especially when it is termed as ‘Low carbon Transport’.

• From the waste management perspective, stockpiling of the auto industry scrap has to be minimized in order to protect the environment, making traffic safer and initiating for better utilization of natural resources and energy sources.

• The TAM (Technology Acceptance Model) based research was, perhaps, for the first time conducted, in the automotive industry under the impact of the I4.0. By the application of TAM present research evaluated the development and effectiveness of the upcoming technological base standing on the I4.0 foundations. Similar efforts are required to be made in terms of the other human-populace of the world also.

• It is worth noting that almost no or hardly few studies on CE based applications pertaining to the two-wheelers are available in literature at the global/national level, whereas India and China are the two giant leaders in two-wheelers’ industry in the world. • There is a need to investigate the impacts of other IT tools also so far as the automotive industry-CE linkage is concerned so as to obtain a generalized and comprehensive report on the matter under reference.

• It may be suggested that simulation tools be used to undertake an in-depth investigation of the disclosed connected aspects. A CLD (Causal Loop Diagram) is also advised for future study on the issue to highlight the interaction among the factors. This can be performed by conducting more interviews with top-level automotive specialists to gain a better understanding of the interrelationships among the issues mentioned. Such a study might give a comprehensive picture of the dynamic interactions between CE execution aspects in the I4.0 area in the Indian automobile sector.

• This information, obtained from the present perception-based research, could help future planners in the car industry understand how stakeholders feel about accepting new technology. It's important to remember that implementing new technology can use a lot of energy and create pollution. This might be one of the first times someone has written about this in literature about Circular Economy and Blockchain Technology (CE-BT). It could be useful for planners who want to introduce digital CE in Indian automotive industry. In the future, researchers might look at how different people involved in the car industry see the impact of CE-BT.

• The research on RRM revealed that the number of returns and recovery of the cars is providing new issues for the researchers of the future as the automotive sector is expanding day by day. With technology improvements, methods may be sought to address the issues that lead to end-users returning unneeded and used goods, minimizing or eliminating the “returns” completely.

• From quantitative analysis viewpoint future researches might be based on the application of environmental scanning with the AHP/affinity diagram employed as a tool for targeting at strategic reversed logistics flexibility-based modelling, equipped with the capability of handling uncertainty, so as to evolve some theoretical framework that provides strategic capability of the future manufacturing entities. This might enable the upcoming generation of enterprises to cope with the uncertain business environment of tomorrow.

It is reported that BS-8001:2017 is the first standard designed for the CE, implying thereby the need to develop such a standard specifically for the auto sector with the shortcomings of the present standard removed. Finally, it is worth noting that, today and in the days ahead, digital technology involving IT tools and their applications find an emerging era of usability, particularly, in the CE based “remanufacturing industry”.

9.5 Social Impact of the Research and Academic & Managerial Implications

Primarily, the present research was planned to study the automotive industry under the shadow of the recently emerging paradigms of CE and the IT tools associated with the I4.0 developments with special reference to the Indian automotive industry. Research questions were formulated in order to address the five research objectives set for this research work. The findings and the implications of the results are comprehensively discussed in the previous chapters contained in the present thesis. The major research contributions which emerged in the form of social impacts along with their academic and managerial implications are briefed in what follows:

9.5.1 Social impacts and the academic implications

The ultimate goal of education in a society is to generate in all walks of life including science and technology, an environment of human-comfort and human-welfare. Present research primarily addressed the issue of scarcity of resources in the future. It is worth noting that the best method would be to keep product-related resources such as material/energy in 'circulation' such that 'waste' is either eliminated or minimized, a technique known as the 'Circular Economy (CE)', that constituted the theme for the present work. Present day’s technological developments have created a major concern for the today’s society as well as for the future generations of the world populace in the form of the huge consumption of goods and the resulting huge stockpiles of the wastes in the form of consumed thrown goods’ waste-materials. According to a recent finding, each year some $2.6 trillion worth of material in fast-moving consumer goods, 80 percent of the material value is thrown away and never recovered. As reported in literature by 2050, the demand for natural resources is expected to get tripled indicating thereby the exceeding importance of either elimination or minimization of waste which is the primary target of CE. The CE-related research found that today's technological world is passing through an era which demands not only 'conservation' but also 'circulation' of resources. It appears that in case of automobiles, only developed nations have taken steps in implementing the CE applications. Thus, underdeveloped countries like India have to initiate 'remanufacturing' particularly in the field of CE-automobiles.

In terms of academic implications, it is worth noting that today's ongoing efforts by the researchers in the fields of CE-RSCL-DT nexus indicate that 'the potential for digital intelligence to enable a regenerative economy is promising'. Present review of the related matter contents indicated the infancy stages for CE-RSCL nexus as well as the emerging IT tools like BDA etc. applications implying thereby in immense scope for their development and growth in the days ahead. The reviewed literature, based on the present research, indicated that the future researchers might address these issues in the days ahead. So far as the challenges are concerned, it is worth noting that more and more precious and valuable natural resources are getting scarcer day by day. Data on CE, analyzed from the perspectives of Indian auto stakeholders using BWM, found that the 'potential' and 'applications' were the most essential. This knowledge could be used by future auto industry planners to determine the intentions of the relevant stakeholders about technological acceptance, having in mind that BT implementation has very high energy consumption costs, which leads to large environmental pollution costs. This could be the first attempt of its like in the CE-BT literature, and it could help future planners of digital CE induction in the Indian car sector. Future researchers may investigate the comparative perceptions of different auto industry stakeholders regarding the CE-BT nexus impacts. The suggested operational paradigm could be useful in this situation.

This study proposes a new CE-BT model that appears to be more reliable and secure than other classical models applied to CE in the automotive sector. Also, the study indicated that the different criteria that were considered weighted differently as perceived by the stakeholders. This could be the first endeavour of its kind in the literature concerning CE-BT, and it might assist future planners in implementing digitized CE practices within the Indian automotive industry. Future researchers might address the issue of comparative perception of different stakeholders of the auto industry where the proposed operational model might be helpful.

9.5.2 Social impacts and the managerial implications

Another critical dimension, in the context of the social impacts, that has been emerging at an exponential growth rate, under the shadow of the ongoing technological developments, is the degradation of the environmental parameters, resulting in imbalancing of the ecological and climatic conditions. In the context of the present research, the need of the hour would be to develop that kind of auto products which enable different components of CE, e.g., recycling and remanufacturing etc. easier. The capturing of the perceptions of the considered stakeholders like end-users and manufacturers indicated that "TOR" (Types of returns) and "IOR" (Influencers of returns) contribute not only to future planning in the auto industry but also to environmental protection, fostering a more sustainable future. Normally, companies do not bother today about what would be the ultimate fate of their products after they are procured by the end-users. A manufacturer may keep a policy of giving its customers rebates for returning end-of-life parts/products/mechanical components so that the manufacturer might be able either to refurbish them for resale at a lower price or entirely dismantle them for the purpose of recycling. The present study revealed that the car manufacturers perception is that employing I4.0 tools may have a significant influence on asset analysis, waste reduction, and management of post-consumer products, whilst end users perceived that I4.0 might be the ideal way to execute new strategies and those using machine tools.

Today, the 'recovery' of materials and 'returns' of goods via the CE component 're-use,' have arisen as a pressing requirement, both in terms of environmental protection and waste management. For sustainable resource utilization, RRM is a component of green technology in the automotive industry, particularly when viewed from the social impact view-point. The findings of this research have significant implications for future policy makers and practitioners in the auto industry. The understanding of end-user perception, as explored in this study, will offer valuable insights for industry managers to effectively retain their customers in the future. Examining how Future researchers might address these issues in the days ahead. The technological world of tomorrow would not be based on the conservation of resources, but it would have to be designed for circulation and recirculation of resources and from this viewpoint the auto industry, like other sectors, would demand a more collaborative environment. Data on CE, analyzed from the perspective of Indian auto stakeholders using BWM, found that 'potential' and 'applications' were the most important. This knowledge could be used by future auto industry planners to understand the objectives of the relevant stakeholders about technological acceptance, having in mind that BT implementation has very high energy consumption costs, which lead to large environmental pollution costs. This may be the first attempt of its like in the CE-BT literature, and it may assist future planners of digital CE induction in the Indian car sector. Future researches can look into the comparative perceptions of different auto industry stakeholders on the CE-BT nexus impacts. In this situation, the proposed operational model could be useful. In the contemporary literature, it is becoming more important to examine how corporate organisations, manufacturers, and end users understand the RRM from sustainability and economic perspectives. Future expectations call for a very lucrative and competitively advantageous automotive sector for all relevant stakeholders thanks to intelligent RRM management based on the cutting-edge IT solutions covered by I4.0. Such evidence is also contained in many studies undertaken in the past.

The cluster analysis yielded valuable results, indicating varieties of variables pertaining to different facets of RRM to be treated at par by the policy planners and the field practitioners in consultation with each other. Perception based RRM studies are hardly available in the literature, particularly in the context of the Indian automotive industry. The findings of the current study about the perspectives of the various stakeholders in the Indian automotive sector should be taken into consideration while designing future policies and realigning the RRM, not only in

India but also in other growing nations like India. As stated under the results' context, the manufacturers' category of stakeholders believed that among the various types of returns in the auto industry taken into account in this study, the TOR spanned over market and product TOR and the IOR spanned over RRM Programme and WEEE influencers. The end-users' group, on the other hand, showed that only "consumer returns" were significant under the TOR dimension of return, and that the IOR variables RRM Programme, hazardous substances directives (HZ), WEEE, and the EPR were major influencers.

9.6 The Research Limitations

First: The present research explored the automotive industry under impacts of the circular economy paradigm and the IT tools associated with the emerging umbrella of the I4.0 with special reference to Indian context. The data collection process remained limited to the Indian automotive industry manufacturers and Indian end-users of its products, Thus, to generalise the findings, it needs to be extended to other nations as well.

Second: The two literature-based and three empirical studies involving model-building contributed to the knowledge enrichment in the academic fields explored in this research. How different variables emerging from the previous researches, as reported in literature, interactively impacted the automotive industry constitute the theme of this research. However, the empirical study-based results remain confined to the automotive industry only. Other industrial sectors also need to be explored in terms of CE applications under the impacts of the emerging I4.0 applications.

Third: The present research involved some perception-based investigations in exploring the CE vis-à-vis automotive industry under the impact the emerging I4.0 era. Perception extraction involves intense collaboration from the respondents especially for strategic situations pertaining to the data collection. The TAM (Technology Acceptance Model) based research was, perhaps, for the first time conducted in the automotive industry under the impact of the I4.0. Similar efforts are required to be made in terms of the other human-populace of the world also. By the application of TAM this research evaluated the development and effectiveness of the upcoming technological base standing on the I4.0 foundations. The results obtained in this study suggest for their adaptability in industrial houses other than those of automotive concerns only on the basis of further research related to the topic.

Fourth: The present research spans over the automotive industry. However, the term automotive industry is a broad term and includes all kinds of vehicles floating in the market. The industry's products are passenger cars, jeeps, buses, mini bases, trucks, mini trucks, tractors, and then two wheelers spanning over motor bikes, scooters etc. In the present research the manufacturers category included only car manufacturers and the end-users included only car driving persons. This indicates a huge limitation of the present research and at the same time offers a wide scope of further research on the related topics. It is worth noting that almost no or hardly few studies on CE based applications pertaining to the two-wheelers are available in literature at the global/national level, whereas India and China are the two giant leaders in two-wheelers' industry in the world.

Fifth: The present research investigated the automotive industry under the impacts of the CE and I4.0 set of emerging IT tools. However, it is important to note that this research included only BT, BDA, IoT and RFI kind of technologies. Therefore, there is a need to investigate the impacts of other IT tools also so far as the automotive industry-CE linkage is concerned so as to obtain a generalised and comprehensive report on the matter under reference.

Finally: The present research focuses on limited number of stakeholders of the auto industry, which can be expanded in the future studies to get more precise results of the investigations undertaken.

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APPENDICES

Appendix-I: Tables pertaining to CE-BT study

Respondents' profiles

(i) For manufacturers of vehicles/parts					
Turnover (in Rupees)	#	*No. of Employees*	#	*India Region*	No. of firms
Less than 100 Crores	0	Less than 50	0	North	7
100-500 Crores	4	50-200	0	East	0
More than 500 Crores	6	200-500	0	West	0
		More than 500	10	South	3

(ii) For end-users of vehicles	
Employers' Turnover	*No. of firms*
Less than Rs.100 Crores	9
Rs. 100-500 Crores	10

(iii) For dealers/suppliers of vehicles	
Dealers' Turnover	*No. of firms*
Less than Rs. 100 Crores	3
Rs. 100-500 Crores	1

Questionnaire

1. CE-BT nexus is drawing considerable attention from academia and industry.
2. BT enables effective 'traceability' of parts/products on the shop floor.
3. BT supports the 'reuse' strategy of CE/Sustainability
4. BT enables ELV (End of Life Vehicles) recovery.
5. The data storage and interaction functionalities needed for CE are seldom employed.
6. Industry persons may not understand the CE-BT nexus.
7. Cost of BT applications in CE is high.
8. BT being a new digital tool, its real impact on CE cannot be assessed.
9. Studying BT impacts on CE involves a lot of uncertainties.
10. Larger digitization like that in BT needs more energy consumption and resource depletion.
11. BT is a digital technology that mainly refers to modern information and communication technology tools that might significantly affect the CE framework.
12. CE-BT has been reported to have been applied in the auto industry. (CE Applications)
13. BT can support all the SDGs (Sustainability Development Goals) set by UNO.
14. CE-BT nexus can support managerial decision making in the auto industry.
15. BT which has been reported to have been initially applied in the 'Bitcoin currency' field is expected to be impacting industry also on a large scale.

APPENDICES

Appendix-II: Tables pertaining to CE-IT Nexus study

Demographic profiles of the respondents: automotive stakeholders

Automotive/Automotive parts' Manufacturers						*Automotive End-Users*	
Turnover (In crores of Rupees)	*Company (No.)*	*No. of Employers*	*No. of Employees' criteria*	*Indian Region*	*Company (Nos.)*	*User-company Turnover (In crores of Rupees)*	*Company (No.)*
< 100	33	22	> 50	North	57	< 100	168
100-500	30	8	50-200	East	7	100-500	21
> 500	35	9	200-500	West	10	> 500	84
				South	24	Others (Unemployed)	21

The Research Instrument (Questionnaire) pertaining to tools 1 (T1) to 20 (T20)

T1	"Asset Sharing" can be facilitated by using IoT technology.
T2	Application of digital technologies like sensors and RFID can reduce waste in production systems and supply chains.
T3	Predictive maintenance schemes can be planned using real-time manufacturing data.
T4	Use of intelligent devices (sensors, recorders, and communicators) can support closing the loop of CE strategies such as repair, reuse, remanufacturing, etc.
T5	The RFID-based real-time shop-floor material management system can be used for monitoring the shop floor continuously for reused materials/parts/products.
T6	The data storage and data interaction functionalities of active RFID tags pertaining to IoT and I4.0 are seldom used.
T7	Active RFID tags, which always have high-volume storage space, ensure smart objects can interact with machine tools, operators, and others to react to unexpected events.
T8	When IoT and RFID are applied in remanufacturing, a large amount of real-time production data is generated and collected to optimize production.
T9	RFID-based remanufacturing data can be extracted from IoT-enabled smart job shops.
T10	IoT facilities such as sensors and actuators can be deployed around the machine tool to sense data such as vibration, humidity, and on-site video, and execute process commands from active RFID tags.
T11	CE strategies can get a boost from the use of IT tools like BDA in providing information on the location, condition, and availability of post-consumption products.
T12	Tools such as 'Waste Stream Analysis' for automotive manufacturers can be employed using BDA for helping design better products for manufacturing.
T13	The End-of-Life vehicles can be recovered through the 'Reuse' strategy by employing BDA algorithms.
T14	Big Data Analytics can be utilized for effective 'Traceability' in your company.

T15	Big Data can be employed for analysing the huge amount of data related to RFID-equipped physical assets which interact with each other to collect real-time production data collaboratively and automatically.
T16	A closed-loop feedback-based emergency inventory control framework supported by BDA technology, by integrating RFID technology for real-time tracking and tracing of reused materials can be the right thing for my company.
T17	Big data can integrate lifelong information and enable to implement new strategies.
T18	Real-time data analytics can enable decision-making for adaptive calibration.
T19	Big data analytics can provide insights both from raw data and also embedded data on multiple machines/equipment/products/objects.
T20	Big data can monitor processes of production and consumption, which eventually allow the material flows to be closed easily.

APPENDICES

Appendix-III: Tables pertaining to RRM study

Participating automotive industry manufacturers and the consumers'/users' profiles.

Manufacturers			*Users/consumers*	
No. of firms	*Firms' Turn over (In Rs)*	*No. of workers in the firm*	*Education (Graduates / Others)*	*Technical / Others*
63	< 500 (in Cr.)	< 1000	Graduates: all	Technical: all
35	> 500 (in Cr)	> 1000	Others: None	Others: None

Questionnaire: Survey-based study examines items, variables impacting returns and recovery process using Q codes.

Q-Code	*The Research Instrument Questions for Manufacturers (M) and Users (U) & EXPLORED VARIABLES (shown in CAPITALS)*
M1	If your company has implemented a RRM PROGRAM for its products/parts, or, if it plans to do so, what is your idea about its success?
M2	The main reason for returned products in your company is MARKET RETURNS (seasonal products, overstock, or unsold products.
M3	The main reason for returned products in your company is CONSUMER RETURNS (damaged delivery, not meeting customer expectations, technical problems).
M4	The main reason for returned products in your company is WARRANTY RETURNS
M5	The main reason for returned products in your company is PRODUCT RETURNS
M6	The main reason for returned products in your company is END-OF-LEASE RETURNS.
M7	The main reason for returned products in your company is END-OF-LIFE RETURNS.
M8	Extended Producer Responsibility (EPR) is among the external factors that can influence the development of RRM.
M9	The Waste of Electronic and Electrical Equipment (WEEE). directive is among the external factors which can influence the development of RRM.
M10	A directive on the elimination or restriction of the use of certain hazardous to humans / detrimental to environment substances (HAZARDS) is among the external factors influencing the development of RRM.

Q-Code	*The Research Instrument Questions for Manufacturers (M) and Users (U) & EXPLORED VARIABLES (shown in CAPITALS)*
M11	Related to the activities in formulating a formal RRM systemin your company, the most important one is SCREENING procedure which influences the identification of how and which products can enter the RRM.
U1	If your company has implemented a RRM PROGRAM for its products/parts, or, if it plans to do so, what is your idea about its success?
U2	The main reason for returned products in your company is MARKET RETURNS (seasonal products, overstock, or unsold products).
U3	The main reason for returned products in your company is CONSUMER RETURNS (damaged delivery, not meeting customer expectations, technical problems).
U4	The main reason for returned products in your company is WARRANTY RETURNS.
U5	The main reason for returned products in your company is PRODUCT RETURNS.
U6	The main reason for returned products in your company is END-OF-LEASE RETURNS.
U7	The main reason for returned products in your company is END-OF-LIFE RETURNS.
U8	Extended Producer Responsibility (EPR) is among the external factors that can influence the development of RETURN MANAGEMENT (EPR).
U9	The WEEE directive is among the external factors which can influence the development of RRM.
U10	A directive on the elimination or restriction of the use of certain hazardous to humans /detrimental to environment substances (HAZARDS) is among the external factors influencing the development of RRM.
U11	U11: Related to the activities in formulating a formal RRM system in your company, the most important one is SCREENING procedure influencing the RRM through identification of how and which products can enter the RRM.
Note:	Response Scale: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree

PROOF OF PUBLICATIONS

International Journal of Sustainable Engineering

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Circular economy under the impact of IT tools: a content-based review

Syed Wasiul Hasan Rizvi, Saurabh Agrawal & Qasim Murtaza

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Automotive industry and industry 4.0-Circular economy nexus through the consumers' and manufacturers' perspectives: A case study

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ABSTRACT

The recent emergence of Industry 4.0 and the circular economy paradigm have significantly influenced various manufacturing sectors, including the automotive industry. These developments pose new challenges and issues in creating a digital and sustainable future. In response, this study was conducted to address the research gaps in perception-based investigations, specifically in the context of the Indian automotive industry. The study explores the impacts of the circular economy-Industry 4.0 nexus on the Indian automotive industry from the perspectives of stakeholders: 98 manufacturers and 294 end-users. Perception data were collected through a structured questionnaire and subjected to statistical analysis using factor analysis (both exploratory and confirmatory) to obtain the best-fit model. The findings indicate that manufacturers recognize the potential impact of the circular economy-Industry 4.0 nexus on waste reduction, post-consumption product management, and asset analysis. On the other hand, end-users perceive that new strategies and machine tool-related aspects are best implemented through Industry 4.0 technologies. Additionally, the study applies the technology acceptance model to bridge the research gap and discusses other enabling factors of the circular economy-Industry 4.0 impacts in the automotive industry. The novelty of this work lies in the first-time application of technology acceptance model in the Indian automotive field. The study aims to identify Industry 4.0 application factors affecting operational efficiency in the circular economy oriented automotive industry, thereby aiding policy planners and managers in developing appropriate circular economy strategies for the digital manufacturing world of tomorrow.

CRediT author statement

Syed Wasiul Hasan Rizvi: Conceptualization, Methodology, Software, Data curation, Writing – original draft preparation. Qasim Murtaza.: Visualization, Investigation. Saurabh Agrawal: Supervision.: Qasim Murtaza: Software, Validation.: Syed Wasiul Hasan Rizvi: Writing – review & editing.

1. Introduction

Today's digital environment based on Industry 4.0 (I4.0) has an important role to play [1]. According to Schwab [2], the I4.0 encompasses "new technologies" that combine the physical, digital and biological worlds impacting all disciplines, economies, and industries. Among the I4.0 technologies, Big Data Analytics (BDA), Blockchain Technology (BT), Internet of Things (IoT), Radio Frequency IDentification (RFID), Artificial Intelligence (AI), and Additive Manufacturing (AM) are the most prominent ones being used in the industry. On the other hand, circular economy (CE) emerging as a new paradigm is the only resort to the challenge of 'scarcity of resources' making human lives unsustainable in the future. CE helps in waste management by circulating/recirculating resources through such strategies as recycling, reusing, or remanufacturing discarded or returned products. Conceptually, CE has already penetrated in varieties of fields. For example, recent researches are demonstrating the CE applications in waste-water management also [3–5]. Recently, circular supply chain enablers were identified by Lahane et al. [6]. Although Awan et al. [7] argue that CE can be risky at times depending upon the stakeholders. The present research is based on a case study of the Indian automotive industry stakeholder's perceptions. The automotive industry in India is growing by leaps and bounds. In 2020, India became the seventh largest automotive market, climbing from the fifth largest back in 2019. It is dominant in the two-wheeler segment because of a largely young and

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Design of circular economy-driven returns and recovery management system in the Indian automotive industry: a case study from stakeholders' perspectives

--Manuscript Draft--

Manuscript Number:	RSER-D-23-05332
Article Type:	Original Research Article
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Keywords:	Stakeholders' perspectives; Return and recovery management; Circular economy; Factor analyses; Indian auto industry
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Abstract:	With the material and energy resources getting depleted fast, sustainability concept is the demand of the day. Returns of goods focusses on the movement and management of products and resources after the sale and after delivery to the customer. In the automotive industry, globally, today, the number of vehicles on roads is close to a billion, with around USD 7 trillion worth of cars reaching their EoL and remaining unused in the future. This presents very sound societal and environmental research gaps and need to be bridged in the days ahead. The present study examines the management of vehicular waste returns in the rapidly growing Indian automotive industry. Perspectives' data from 96 manufacturers and 294 end-users were collected through structured instrument and analysed using exploratory and confirmatory factor analyses, along with cluster analysis to achieve the best-fit model. The findings provide unique insights into returns and recovery management, contributing to the understanding of environmental sustainability and the circular economy. The novelty and originality of the present research lies in the development of an understanding of the auto industry stakeholders' perspectives on the 'types of returns' and 'influencers of returns' so as to help the future policy planners in evolving the optimum strategy for the returns and recovery management system in the Indian automotive industry in the days ahead. With implications for the eco-friendly automotive sector, particularly in India, this research advances knowledge in redesigning the returns and recovery management system, promoting environmental sustainability in the automotive industry.

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Engineering Software Expertise/Training:

PVSyst, FMS systems with SCORBOT ER V, CATIA software used for designing 3-D mechanical parts, Reverse Engineering Lab using Hand Scanner used in Catia, ABAP/4 programming in SAP/R3.

Research Papers Published/Accepted/Communicated in Conferences/Journals:

20 International & 4 National level papers.

Software Expertise/Knowledge:

Some coding/implementation experience in SPSS, SPSS-AMOS, CMMS-MP2, ABAP/4 Programming, mySQL, JDK 1.2, RMI, Servlets, Applets, JDBC, JavaScript, C++ while some basic knowledge in EWM, Google BigQuery and Data engineering.