An Environmental-Based Perspective Framework: Integrating IoT Technology into a Sustainable Automotive Supply Chain

Abstract

Purpose - Over the next decade, humanity is going to face big environmental problems, and considering these serious issues, businesses are adopting environmentally responsible practices. To put forward specific measures to achieve a more prosperous environmental future, this study aims to develop an environment-based perspective framework by integrating the Internet of Things (IoT) technology into a sustainable automotive supply chain (SASC).
Design/methodology/approach - The study presents a conceptual environmental framework - based on 29 factors constituting four stakeholders' rectifications - that holistically assess the SASC operations as part of the ReSOLVE model utilizing IoT. Then, experts from the SASC, IoT, and sustainability areas participated in two rigorous rounds of a Delphi study to validate the framework.
Findings – The results indicate that the conceptual environmental framework proposed would help companies enhance the connectivity between major IoT tools in SASC, which would help develop congruent strategies for inducing sustainable growth.
Originality/value - This study adds value to existing knowledge on SASC sustainability and digitalization in the context where the SASC is under enormous pressure, competitiveness, and increased variability.

Keywords: Environment Sustainability; Business Strategy; Sustainable Automotive Supply Chain; Internet of Things

Paper type Research paper

1. Introduction

In the last decade, the topic of sustainability has grown in significance in the context of supply chains (Yadav et al., 2020). The constant escalation of competition among organizations on a global scale has compelled them to adopt sustainability practices to maintain stability (Manavalan and Jayakrishna, 2019). Sustainability is ingrained from the conception of an idea to the delivery of the finished product to the customer (Bai et al., 2020). Several researchers studying Sustainable Supply Chain Management (SSCM) have put forth frameworks to increase SSCM adoption rates, including (Mastos et al., 2020) and (Accorsi et al., 2018). However, it is important to note that the current business environment is rapidly shifting towards digitization, making it challenging for organizations to adopt SSCM alongside conventional supply chain and sustainability practices (Mastos et al., 2020).

Research on Industry 4.0 (I4.0) and sustainable supply chains has significantly increased (Bai et al., 2023; Ching et al., 2022; Mastos et al., 2020). Internet of Things (IoT), Big data analytics, simulation, deep learning, and forecasting techniques are used to address the modern needs of supply chains, such as flexibility, waste reduction, productivity gains, resource optimization both inside and outside of factories, and more environmentally friendly manufacturing processes (Dev et al., 2020; Manavalan and Jayakrishna, 2019; Yadav et al., 2020). Due to pressure from various stakeholders, including customers and investors, sustainability has emerged as a crucial business issue, prompting organizations to establish more sustainable practices both internally and throughout their supply chains. A framework that connects SSCM challenges with its solution measures was proposed and tested by (Yadav et al., 2020). The results of their study showed that managerial and organizational issues are what most often lead to SSCM failures, while a lack of technical, financial, and human resources limits sustainability. According to (Agrawal et al., 2022), the key elements of a global SSCM are SSCM configurations (open, closed, and third party), as well as SSCM governance mechanisms (such as supplier collaboration and evaluation). Implementing solutions that use smarter devices and the digitalization of business and manufacturing processes are anticipated to positively impact resource optimization, production capacity, and waste reduction (Mastos et al., 2020). According to recent studies, "manufacturing businesses must speed up the shift in focus toward sustainability while employing technology like IoT to achieve their strategic business goal" (Manavalan and Jayakrishna, 2019).

In light of this, the solutions that use Industry 4.0 technologies are recognized as crucial elements for the effective development of SSCM. The literature has developed a number of models that combine these two concepts. (Ching et al., 2022; El Jaouhari et al., 2022), for instance, provided a framework connecting SSCM and Industry 4.0, whereas (Alharthi et al., 2020) looked into the effects of a specific Industry 4.0 technology (Blockchain) on the shift toward sustainable development. Within this perspective, sustainable development, supply chain, and Industry 4.0 practices are investigated by (Bai et al., 2023), who found that supply chain transparency, reuse, and recycling are crucial procedures for manufacturers looking to increase sustainability. By reducing waste, optimizing resource consumption, enhancing supply chain communication, and lowering carbon footprint, Industry 4.0 technologies like IoT improve sustainability performance (Cavalieri et al., 2021).

One of the fastest-growing sectors with the development of IoT is the automotive sector. According to market estimates, there will be about 310 million vehicles with IoT capabilities by 2023 (Krasniqi and Hajrizi, 2016; Rahim et al., 2021). In regards to financial value, Reuter's research on the Global Automotive IoT emporium forecasted a massive increase in the IoT Market price would increase to $100.93 billion by 2023 from $20.49 billion in 2016 (Reuter, 2016). In this situation, the IoT technology can have a significant impact in improving general ease of transit and travel activities efficiency by utilizing an intelligent transportation system (ITS) to reduce disrupted travel and accident rates through accurate data exchange among motorists and other pertinent authorities (Alkinani et al., 2022; Rajabion et al., 2019). Additionally, in smart automotive manufacturing, IoT can also be used to offer insightful vehicle problem detection enlightening car problem diagnosis, and productivity and maintenance refinement (Ashima et al., 2021; Qazi et al., 2022). As a result, IoT devices in the automotive industry are becoming increasingly popular, as seen by intelligent transport planning (Levina et al., 2017), vehicle condition monitoring (Fahmi et al., 2019), and industrial activity monitoring (Wong et al., 2021). For instance, the broad adoption of cutting-edge communication technology in industrial processes for speeding up and monitoring production processes, inventory control for spare components, raw materials management, sales management, and after-sales supervision of automotive parts is a viable choice (Ching et al., 2022; Saravanan et al., 2022).

According to the authors (Carayannis et al., 2018; Laroui et al., 2021; Pal et al., 2022), by 2023, IoT will have contributed more than $14 trillion to the economy, with approximately 34 billion embedded devices in various domains such as smart grids, city infrastructure, home/residential automation, industrial systems, transportation, healthcare, military, and so on. IoT simply equips gadgets with specialized sensors that allow them to communicate and assist users in participating actively in information networks (Zhu and Zhao, 2018). IoT makes stand-alone devices smart and connected, facilitates material tracking, and aids in the assortment of outdated products and trash management (Lin et al., 2019). As a result, remanufacturing, reusing, and recycling services close the loop. Organizations and firms would be capable of gathering a significant amount of information quickly with this new method (Manavalan and Jayakrishna, 2019). Furthermore, IoT enables manufacturers to keep an eye on the operations of their products, providing data that aids in providing better technical assistance (Venkata Lakshmi et al., 2021). End-of-life and renovation activities can benefit from the IoT. Monitoring the status of items, according to Raghu, (2018), is critical for any company. Thus, IoT could be a useful technology that allows companies to monitor their devices' usage, location, and status in real-time throughout their product lifecycle (Menon et al., 2022). Manufacturing managers can learn more about how customers use and deploy their goods in this manner, allowing them to get closer to them (Manavalan and Jayakrishna, 2019). As a result, producers and their customers will have beneficial contacts.

Although earlier studies on SASC and IoT have produced useful findings as per research gaps (as shown in section 2.5), the body of literature is still limited, and more research is needed to fully understand how IoT will affect SASC (Mastos et al., 2020; Mathivathanan et al., 2018). The study by (Vieira et al., 2019) has also brought attention to the need for improved SASC model validity analysis. As a result, more research is needed to investigate the issues that impede the acceptance and use of the IoT-enabled SSCM.

Therefore, using a combination of the ReSOLVE model and the Delphi approach, the current paper aims to propose a theoretical framework for the incorporation of IoT technology to create a SASC, specify a probable course of action, and rank any hazards that might develop over this accession process. Through existing literature, the Delphi technique aids in the finalization of the driving attribute of IoT in the automotive supply chain (ASC) (Gebhardt et al., 2022). The ReSOLVE model, on the other hand, uses the key concepts of circularity to apply them to six actions: Regenerate, Share, Optimise, Loop, Virtualize, and Exchange, to assist in answering long-term planning problems about renewables integration in ASC (Dev et al., 2020). In this context, the current ASC will be investigated in this framework, and the operations will be categorized according to their strategic and technological sustainability. A framework will then be provided, which involves the adoption of IoT technology across all functions with the aim of addressing the following research questions (RQs):

RQ1: How does IoT adoption help achieve sustainable automotive supply chain practices (SASC)?
RQ2: Why are IoT solutions essential to achieve sustainability in ASC?
RQ3: How can IoT and sustainable development practices be combined to achieve an effective SASC for stakeholders?

Accordingly, this research aims to investigate how IoT is currently used in SASC and how IoT may help SASC. This study proposes a system for identifying IoT-enabled SASC and enabling case mapping based on IoT capabilities. Furthermore, this study stands out from other recent reviews in that it focuses on the development of IoT tools for the automotive industry and related connectivity technologies (Rahim et al., 2021; Turner et al., 2022). This is achieved by gathering the essential information from existing research projects and envisioning potential future study directions. For example, previous IoT reviews for the automotive industry focused on specific topics including a survey on critical technologies (Halili, 2020), an intra-vehicular network assessment (Ashjaei et al., 2021), a review on car parking systems (Zhang et al., 2020), and succinct descriptions of limited automotive IoT implementation (Rahim et al., 2021; Turner et al., 2022). This study goes a step further by bringing together a diverse set of automotive IoT networks and integrating them with other research articles, such as important vehicle tracking (Sugumar et al., 2020), accidental position detection (Rahim et al., 2021), vehicle burglary prevention (Sathiyanarayanan et al., 2018), vehicle performance observation (Shao et al., 2019), smart city traffic management (Balakrishna and Thirumaran, 2018), automotive industrial management (Malik et al., 2021) and so on. This effort is expected to capture new and evolving IoT tools in the ASC, laying the groundwork for the ASC 's recent adoption of IoT as it moves toward Industry 4.0.

The research is structured as follows. Section 2 is a literature review that discusses the theoretical underpinning of IoT in the SASC and proposed methods. The approach utilized in this study is discussed in Section 3, and the study's results are reported in Section 4. The current study's discussion and implications are explained in Section 5. Finally, the last section discusses limitations, potential research prospects, and conclusions.

2. Literature review

It is clear that there is growing interest in the fields of SASC and IoT, as previously stated in the introduction. This observation is supported by a recent study by (Manavalan and Jayakrishna, 2019), which demonstrates an expanding but still modest trend in SASC research and IoT. 128 papers were published in 2018 compared to just 8 papers in 2009 (Manavalan and Jayakrishna, 2019). This demonstrates that this area of study is still developing. To support decision-making in manufacturing operations and procedures, a number of Industry 4.0 and IoT solutions have been developed. (Manavalan and Jayakrishna, 2019) emphasize the importance of putting a high priority on sustainability while utilizing cutting-edge technologies like the IoT to meet customers' needs, organizations' objectives, and rapid changes in market dynamics. An overview of SASC and its applications for IoT is provided in this section.

2.1 Automotive supply chain

The automotive supply chain (ASC) is a complex network of stakeholders, manufacturers, distributors, retailers, regulatory organizations, and insurance firms, as well as a diverse range of car parts (Teucke et al., 2018). ASC is also well laid out and well-managed using conventional methods. There is a huge chance to create a unified source of actuality/data throughout the supply chain through the incorporation of IoT into current procedures (Mastos et al., 2020; El Jaouhari et al., 2022).

2.2 IoT tools

IoT tools are being used in many different industries thanks to the development of Industry 4.0. These technologies, as well as their capabilities, are presented in the following sub-sections. This knowledge will be needed later to comprehend the importance they give in terms of supply chain transparency and connection. Figure 1 below provides a summary of the major IoT tools.

2.2.1 Global positioning system

One of the technologies used by businesses to track automobiles, trains, trucks, and ships in real time is the Global Positioning System (GPS) (Brennan et al., 2019). Some advantages of using GPS technology for tracking include the following: improved delivery efficiency by identifying bottlenecks, faster issue diagnosis, improved information for planners, enhanced customer satisfaction, and rapid reaction times in the event of delays (Gharajeh and Jond, 2020). However, if the GPS receivers are located indoors, they will be unable to communicate effectively with satellites to deliver accurate location data (Benachenhou and Bencheikh, 2021). By connecting GPS mapping systems to ERP systems, it may be able to improve logistic scheduling (Srinivasan et al., 2003). Transparency-enhanced decision-maker efficiency, higher transportation capacity, urban transportation optimization, dynamic product routing, automated exception reports, and online decision support for transportation will all benefit from its use (Sirish Kumar and Srilatha Indira Dutt, 2020). Businesses employ telematics and automatic identification systems (AIS) to track deliveries in real-time throughout the supply chain system, both of which offer similar advantages (Papert et al., 2016).

2.2.2 Vehicle telematics

The adoption of Information and Communications Technology (ICT) in transportation is also known as (advanced transport telematics), which offers a variety of solutions for rail, road, air, and sea transportation, as well as information technology and telecommunications (Hamidi et al., 2016). Despite including all forms of transportation, the term is most frequently used to refer to the vehicle telematics software employed in the sector of road transportation. (Janecki et al., 2010). The primary purpose of vehicle telematics systems is to transmit and store data so that drivers may monitor routes and send services like digital distribution notes, sales orders, and recorded data (Hu et al., 2022). The second important element of automobile telematics systems is the internal monitoring devices that gather data about the vehicle (Ußler et al., 2019). Increased availability of vehicle technology providers ensures improved fleet control in terms of automotive diagnosis, automotive service, driving monitoring, safety, and health administration, fuel management, and complicated vehicle programming using real-time common knowledge (Wang et al., 2020). One key result is that the ecological damage is decreased. The utilization of real-time data also enhances the improvement of the estimated time of arrival (EIA) forecasting in road transportation networks (Boufidis et al., 2020).

2.2.3 Automatic identification system

The marine sector uses the Automatic Identification System (AIS) to gather data on ships (Meyers et al., 2021). The identification, position, type, course, navigational status, and speed of a ship are all automatically provided by AIS (Le Tixerant et al., 2018). This data can then be used to predict delivery timings and enhance supply chain management. More and more often, the AIS data is used to monitor ecological impacts (Stopka et al., 2019). The International Maritime Organization (IMO) has mandated that AIS be installed aboard ships since 2002 (Robards et al., 2016).

2.2.4 Radio-frequency identification

Wireless information and Communications Technology is a radio frequency identification technology (RFID) that does not need mechanical or physical touch and instead writes and reads data via radio waves (Tanner, 2016). RFID consists of a wafer-based label attached to an antenna, a radio transmission scanner that collects data from labels, and software that connects to enterprise systems (Fan et al., 2015). In a cost-effective framework, RFID technology can be utilized to recognize and connect equipment and artefacts with networks and databases (Oluyisola et al., 2018; Arif et al., 2019). The data accessible in RFID technology is crucial for improving Supply Chain operations by enhancing supply chain transparency and integrating supply chain players (Pal, 2019). According to (Liukkonen, 2015) surveys, RFID can provide various benefits for supply chain management, including improved visibility and traceability, improved performance, reduced inventory losses, higher information quality, and current data. Overall, RFID is utilized in supply chains to track items, reusable assets, cases, and pallets like containers and racks. One of the most significant disadvantages of an RFID system is that once recorded items exit the factory or warehouse, they will be postponed until the goods are linked and the following halt on the supply chain is achieved (Garrido Azevedo and Carvalho, 2012).

2.2.5 Smart sensors

Smart sensors include, for instance, humidity, influence, and temperature sensors that are used to track alterations to the environment and the condition of items (Frank, 2013). This data, paired with IoT, may be interchanged among Supply Chain Partners to ensure that items and materials are moved without changing humidity, temperature, or quality (Zhang and Sakurai, 2020).

2.2.6 Camera-based systems

Camera-based data collecting delivers useful information in addition to traditional methods of data collection (Fahmy et al., 2020). Image processing algorithms can perform a variety of activities, from basic product recognition to advanced camera-based impulses (Demirhan and Premachandra, 2020). Four properties can be utilized to detect and track artefacts: edges, colours, texture, and movement (Kim et al., 2016). Many application areas are included in camera-based systems, including object numbering as they enter your camera view zone, monitoring storage regions, object positioning, load-behaving status monitoring, and package path tracking (Raphael et al., 2011). Increased visibility is a common goal for all visual component applications, which is frequently complemented by efficiency advantages (Hautiere et al., 2010). Information may be continuously extracted using the camera-based system, allowing for inventory management and real-time status tracking (Fahmy et al., 2020).

2.2.7 Smart contracts

Smart contracts are sequence lines of blades that are recorded on a Blockchain and are then implemented when predefined conditions and criteria are fulfilled (Almakhour et al., 2020). Smart contracts can be used to construct transparent automated and digital decision-making for any implementation that requires rigorous examination with a variety of criteria (Almasoud et al., 2020). In the automotive industry, smart contracts are crucial for resolving difficulties like just-in-time inventory, supplier evaluation systems, supply methods, master agreements and purchase orders, legal avenues for relief, contract regulation dividing, and precise and explicit terms in specifications (Ferreira, 2021).

Figure 1. IoT tools (Source: Created by authors)

2.3. Sustainable automotive supply chain and IoT tools

The literature has identified a number of variables that can either positively or negatively affect SASC adoption. For instance, two of the key SASC enablers are cost savings linked to operational and material efficiencies (Vieira et al., 2019) and increased resource utilisation (Marodin et al., 2016). In addition to forecasting accuracy, which lowers or eliminates waste production, is a crucial supply chain factor for SASC (Teucke et al., 2018). Information sharing is another significant factor that enables SASC (Kirk, 2015). Contrarily, pressures from various stakeholders, including regulatory bodies, Non-Governmental Organizations (NGOs), community organizations, suppliers, and customers, as well as factors like global competition, a lack of adaptability, and delayed market entry, have forced businesses to re-evaluate how to balance environmental, social, and economic issues in their operations (Agrawal et al., 2022; Bai et al., 2023). In fact, according to (Accorsi et al., 2018; Dev et al., 2020), the complexity and dynamic nature of these factors may make supply chains more uncertain. Applications of Industry 4.0 technologies have been proposed and implemented to change supply chains and build digital networks in order to address these issues (Ching et al., 2022; Yadav et al., 2020). For instance, the ability of automotive Original Equipment Manufacturers (OEMs) to embrace change in the digital era will determine their survival (Tarasov, 2018). Companies are transitioning to a digital strategy by exploiting a substantial amount of data obtained in the ASC via IoT, including information from the production plant, final items, processes, consumer consumption habits, and logistics (Banerjee, 2019; Kirk, 2015; Turner et al., 2022) (RQ1). However, this information is useless until it is structured, decrypted, and thoroughly studied for implications. Data is the oil industry in this ever-evolving digital world, and it has the potential to substantially alter business processes (Cano et al., 2018). However, under current procedures, the benefit of using this new oil is undervalued. The ASC faces numerous difficulties that go unnoticed and require special care from its partners, among them is the ecosystem's closed nature (Yadav et al., 2020). The automotive sector is currently moving toward electrification, which will require modernizing the existing supply chain (Casper and Sundin, 2021). A battery, which will serve as the primary engine element of the Electric Vehicle (EV), will replace an interior burning engine, for instance, which currently needs many parts from multiple retailers (Kalaitzi et al., 2019).

The ASC's complexity stems from several variables, including the presence of several middlemen, huge geographical distances, and multiple layers of vendors with vast supplier standards (Marodin et al., 2016). The recorded data contains uncertainties and duplicates, and the same knowledge is being used for a complete investigation of the ASC system (Vieira et al., 2019). Furthermore, the automotive sector is poorly unprepared for the exchange of actual data among stakeholders, and traditional devices are incapable of conveying accurate information about items to final consumers, and the authenticity of data is not confirmed anywhere in the supply chain (Zailani et al., 2015) (RQ2).

However, stakeholders need a deeper grasp of the automotive ecosystem to address the difficulties of ASC (Datta et al., 2017). The majority of automotive businesses are working on developing new cutting-edge technology to continuously collect huge amounts of information and aid in asset management (A.S. and Ramanathan, 2021). Nevertheless, for further synthesis, the complete data must be joined together, properly controlled, healed, and handled in a decentralized context. Sensors with high sensing capability, computing embedded devices, and latency-free data gathering systems are examples of IoT tools, that may interact with other gadgets for actuation and link persons over the net (Mohanta et al., 2020). In addition, information from supply chains can be exposed to sophisticated analytics for information-driven decision-making and near-real-time end-to-end transparency.

2.4. IoT and sustainability barriers for ASC

The growing concept of IoT and sustainability is emerging as a way to minimize the adverse environmental effects of businesses. IoT-related technology such as RFID, smart sensors, GPS, etc., can remain connected while offering crucial information across the entire lifespan of products (Mosallanezhad et al., 2023). According to (Qi et al., 2023), implementing IoT for a sustainable supply chain presents strategic, organizational, ethical, technological, and regulatory challenges. They also outlined the major issues encountered by sustainable manufacturing operations. The primary barriers to IoT adoption are a lack of support from governments and regulations, a lack of data-sharing protocols and global standards, and financial limitations. (Hegab et al., 2023) emphasized the technological, cultural, market, and legal barriers preventing the widespread adoption of sustainability. The high cost of adopting sustainability, the scant supply of virgin materials on the market, and the lack of financial subsidies have all been identified as major challenges to the implementation of the sustainability concept. The issues that the automotive industry faces in achieving Industry 4.0 and meeting environmental protection goals were noted by (Rizvi et al., 2023). The study highlights how crucial integrating technology is to enabling recycling, reusing, and remanufacturing capabilities. Barriers were emphasized through the lens of the "economic aspect," "cultural aspect," and " legal and technological aspect". The outstanding issues and primary challenges with the IoT when incorporated with sustainability are examined in (Pouresmaieli et al., 2023). Based on the analysis performed, the primary barriers to the integration of IoT-sustainability are bandwidth management, security, connectivity, interfacing interoperability, data processing, and packet loss. According to (Wissuwa and Durach, 2023), there are concerns with the implementation of sustainability in the German ASC as a result of ineffective government regulations, a dearth of manufacturers' knowledge, and a lack of technique and technology. The political/government, environmental, financial, infrastructural, legal, and technological challenges when integrating a sustainable supply chain with technology in the automotive industry were highlighted by (Kamble et al., 2023). In light of the IoT - IoT-sustainability adoption, (Dutta et al., 2023) highlighted sustainable SC challenges and presented their resolution procedures. The primary challenges identified in the study were a lack of human and technological resources, a lack of financial support, a lack of management involvement in adopting sustainability, and conflicts among sustainability policies. (Mathiyazhagan et al., 2023) identified regulatory uncertainty, a lack of government regulation, and stakeholders' mistrust as major challenges to the implementation of sustainability practices in multi-tier Indian automotive manufacturing firms.

2.5. Research gaps

Previous research has shown that IoT solutions are being used in a variety of industries and have the potential to convert conventional supply chains into sustainable supply chains (Manavalan and Jayakrishna, 2019; Ali and Ali, 2021; El Jaouhari et al., 2023). Although various Industry 4.0/IoT opportunities exist for developing SSCM, there is still a limited connection between theoretical advancements and practical applications. The introduction of IoT tools and sustainability may present new issues for ASC. Hence, it is becoming more important to investigate how these factors affect ASC.

Furthermore, industry-specific investigations are still scarce. To shed light on the identified research gap, we propose a conceptual framework for integrating IoT technology into a SASC, outline possible actions, and rank any risks that might develop throughout the integration process. Prioritization is also necessary to maximize the effectiveness or worth of each action. This justifies the goals set for the current research work.

3. Research methods

Prior research has focused on analysing either quantitative or qualitative data to establish a meaningful connection between the concept of IoT and ASC development. Due to the linguistic ambiguity in the existing literature, there are still gaps in the characterization of this interaction (Birkel and Hartmann, 2020; Raj Kumar Reddy et al., 2021; Ramirez-Peña et al., 2020). Moreover, adequate interviews with key players and a grasp of the relationships among qualities are lacking in the literature, which would offer insights into the complexities inherent in real-world problems. (Müller, 2019), for instance, conducted in-depth interviews with top management to identify the elements that drive and challenge I4.0 adoption. Aside from that, other multicriteria decision-making techniques, such as Analytic Hierarchy Process (AHP) and Technique of Order Preference Similarity to the Ideal Solution (TOPSIS), have failed to uncover the causal linkages between criteria that may be easily established using the Delphi Technique (Asghari et al., 2017). The analysis in this paper relies on a mix of the ReSOLVE paradigm and the Delphi approach.

3.1. Delphi study

The main objective of the Delphi method is to forecast future events (Holey et al., 2007; Sumsion, 1998). It is an empirical technique that relies on professional opinions to promote consensus-building and structured group discussion on a particular subject (Skulmoski et al., 2007). According to (Skutsch and Schofer, 1973), expert opinions can be expressed qualitatively (e.g., comments supported by reasoning) or quantitatively (e.g., Likert scale ratings). Its round-based methodology enables individual reevaluation of estimates, participant interaction, and continuous reflection on the responses (Day and Bobeva, 2005).

The Delphi method has four main benefits. First, it is a tried-and-true method for researching future scenarios with high levels of uncertainty, especially in SCM (Melnyk et al., 2009). Second, the Delphi method is a precise approach for investigating contexts where there is not enough empirical data and where expert knowledge is the only trustworthy source of data (Skulmoski et al., 2007). Third, compared to individual assessments like semi-structured interviews and other types of group assessments, the Delphi approach enables the gathering of knowledgeable opinions from a variety of experts (Day and Bobeva, 2005; Holey et al., 2007). Fourth, the method's assurance of anonymity guards against unfavorable group dynamics like bandwagon and halo effects (Day and Bobeva, 2005; Sumsion, 1998).

In the current study, a two-round Delphi study was used to validate the conceptual framework. A Delphi technique entails asking a set of people to confidentially answer a series of queries on an individual statistical estimation, like the chance of an incident happening or the timing of its occurrence. The responses are then combined, or aggregated, by a facilitator into a statistical summary of the group answer, perhaps with the explanations for the reactions included (Belton et al., 2019). Further, (Belton et al., 2019) proposed that participants are then given the option of submitting a revised answer or resubmitting their initial response after evaluating the diversity of responses received. This repetition and controlled feedback mechanism go over several 'iterations' until a consistent pattern of replies emerges, such as an obvious agreement or significant dissension. The experts from the ASC, IoT, and sustainability areas have participated in this study. Also, experts are from both industry and academia to avoid the biases of theoretical and practical implications of the framework. Figure 2 depicts the Delphi technique used for framework validation.

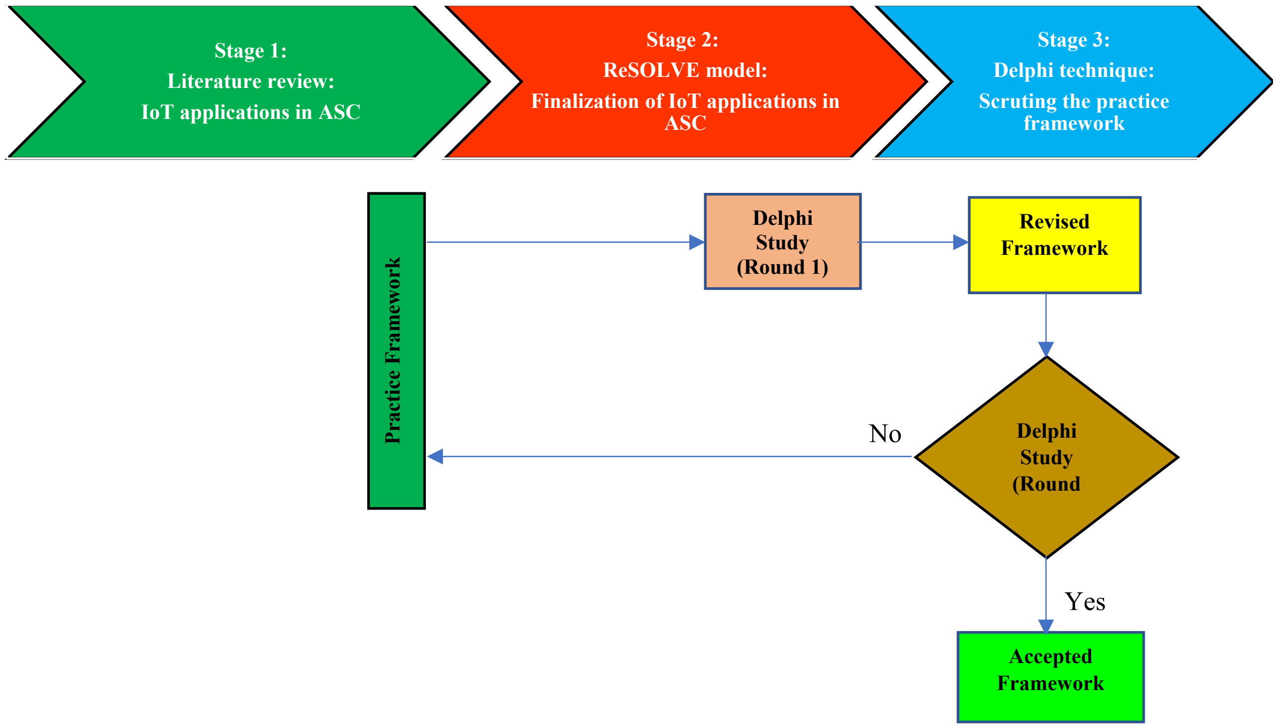

Figure 2. Research Methodology (Source: Adapted from Norani et al., 2012)

The 5-point Likert scale is used for this study because it is a psychometric scale utilised in responses to questionnaires to estimate perception (Wadgave and Khairnar, 2016). Consensus (harmony) is the projection of the majority opinion of experts with their agreement on that particular subject and presented in percentage. (Foth et al., 2016) indicate the threshold value of agreement acceptance among participants is a minimum of 75%. So, the study has taken the minimum threshold of 75% for this study, which means the questions score greater than 75% will come under the consensus. The score of individual queries is calculated as follows:

- First, calculate the average of multiple responses for a particular question.

$$\boldsymbol{Average} = \frac{\sum_{0}^{n} \boldsymbol{response\ index}}{\boldsymbol{n}} \quad \textbf{(1)}$$

Where n = number of expert responses

- Second, calculate the percentage from the average

$$\boldsymbol{Percentage} = \frac{\boldsymbol{Average}}{\boldsymbol{m}} \quad \textbf{(2)}$$

Where m= maximum numeric value of scale, which is ‘5’ in this case.

The questionnaire presents four sections (stakeholders' rectifications) and 29 factors representing the stakeholders' rectifications. The conceptual framework was demonstrated to the experts to understand the study better. The experts were selected from various professional platforms such as ResearchGate, Google Scholar, LinkedIn, University webpages, and Conferences. The research has chosen 78 experts and decision-makers in areas like sustainability and the automotive industry contacted via email. Out of 78 experts, 37 agreed to share in this study (see Appendix A). The survey validation was done by pilot testing with 15 persons, and they have no background related to ASC, IoT, and sustainability. This way, the questionnaire was verified with no grammar errors, and it was conducted in one month. After the pilot testing, the questionnaire was sent to experts for their responses. Therefore, the first round of the Delphi study was conducted in three months max. The profile summary of experts and their response rate is given in Table 1.

Table 1. Experts participated in the Delphi study (Rounds 1 & 2) (Source: Created by authors)

S. No.	Experts	Total Respondents Contacted (Round 1)	Received Response (Round 1)	Total Respondents Contacted (Round 2)	Received Response (Round 2)
1.	Supply chain consultants	10	7(70%)	7	5 (71.42%)
2.	Academia Experts	15	7 (46.67%)	7	7 (100%)
3.	IoT consultants	11	6 (54.54%)	6	5 (83.33%)
4.	Industry experts	25	10 (40%)	10	9 (90%)
5.	Sustainability consultants	17	7 (41.17%)	7	6 (85.71%)
	TOTAL	**78**	**37**	**37**	**32**

For, the round 2 Delphi study, contact was established with 37 experts, and only 32 experts responded and agreed to take part in this study. This study was conducted over two months.

3.2. ReSOLVE model

The Ellen MacArthur Foundation (Sillanpaa and Necibi, 2019) established the ReSOLVE model, which illustrates how the six aspects of regenerate, share, optimize, loop, virtualize, and exchange is conceived into circular economy business practices.

• *Regenerate* This is due to a change in materials and energy to renewable sources. Biological cycles are utilized to allow materials and energy to circulate, as well as to transform organic waste into raw materials and energy for subsequent chains (Kouhizadeh et al., 2020).

• *Share* This is built on a sharing-economy model, where ownership is minimal and goods and resources are shared among people. Products should be designed to last longer as a result, with maintenance options accessible to encourage reusing them and extending their useful lives (Kouhizadeh et al., 2020).

• *Optimise* A technology-driven process. To eliminate waste in production systems throughout supply chains, this approach needs firms to integrate digital manufacturing technology such as automation, sensors, RFID, remote guidance, and big data. The increased performance will help organizations; for instance, a predictive maintenance program could be established using factual data regarding equipment status (Kouhizadeh et al., 2020).

• *Loop* This is based on cycles in biology and technology. Anaerobic treatment is vital for recovering the potential of biowaste, and technological processes like reuse, repair, remanufacture, and recycling may do the same for packaging and post-consumer goods. These options have been investigated using operations research methods (Kouhizadeh et al., 2020).

• *Virtualise* A service-oriented strategy that emphasizes dematerialized and virtual products over physical ones (Kouhizadeh et al., 2020).

• *Exchange* This entails replacing non-renewable items with sophisticated and renewable alternatives (Kouhizadeh et al., 2020). By using a system dynamics model. (Keilhacker and Minner, 2017) show that replacement has a large power to minimize supply chain instability induced by the usage of scarce earth resources. The matrix in Table 2 was created by connecting ASC Key stakeholders (suppliers, Vehicle manufacturers, customers) to the six business strategies provided by the ReSOLVE model; we also provide the IoT characteristics for each interaction.

Table 2. Relational Matrix illustrating the intricacy of linking IoT and ASC (Source: Created by authors)

ReSOLVE	Key stakeholders (suppliers, Vehicle manufacturers, customers)	Essential characteristics of IoT
Regenerate	Suppliers will need updated information about a variety of renewable, alternative, and less impacting raw materials, in collaboration with manufacturers – notably focal companies.	Product lifecycle management (PLM) concept assisted by IoT to enhance product design, such as replaceable or modular components, Operational efficiency, and Cyber resiliency. There is no requirement for intermediaries that do not bring value, simple and fast exchange with low fees Digital business operations using IoT enablers and smart contracts, Reduction in human errors
Share	Customers will be critical in gathering information about goods that are ready to share.	Intelligent devices turn trash into valuable resources, and data on post-consumption items are made available for proper ordering operations, allowing for cooperation and integration in the ASC. Business competition (e.g., enhanced cybersecurity, lower transactional expenses, complete IoT integration), diversity of markets (e.g., encouraging car sharing), Enabling novel business models, Restoring the balance of information among stakeholders
Optimize	Manufacturers will play a critical role in creating a waste-free manufacturing/supply system. Waste information (both created and prevented) and its impact on business performance will be critical.	The product's end-of-life is evaluated from a remanufacturing standpoint, necessitating collaboration across ASC partners made possible by IoT. Each key asset's full provenance and traceability information Access to information is available to all stakeholders (e.g., producers, car owners, vendors, insurance organizations, and government controllers)
Loop	Keeping materials in closed loops will need shared data among all three stakeholders. Information on product traceability across their life cycles and loops will be crucial.	Accountability, timestamped, verified, and auditable immutable data, No data has been lost, altered, or faked. Modern cryptography and Security, Non-repudiation, Global accessibility Transparency
Vertualise	the acceptability of virtualized services Understanding consumers' needs and products is at the centre of this ASC strategy. Producers will want accurate information on consumer preferences.	IoT devices replace the physical world with the virtual world. Asset provenance and Traceability, Fluid value exchange and Dynamic Proof of ownership, rights, and accountability.

Exchange	Producers will be critical in unlocking this plan since they can replace outmoded processes with more sustainable ones.	The virgin new items are replaced by the remanufactured (green) items. The traditional push approach of manufacturing is being replaced by a pull system that allows for mass customization. This is accomplished by smart connected items that connect to the IoT and a CPS system that collects data for the ASC.

3.3 Proposed framework

As previously discussed, the ASC is operating in an unpredictable world, and IoT is becoming more essential for ASC operations every day. Three categories can be used to categorize the ASC's current and prospective IoT uses: accurate commercial and industrial supervising (Zhao et al., 2019), real-time vehicular monitoring (Pendor and Tasgaonkar, 2016), and real-time transportation management (Chauhan et al., 2020). The concept showed employing IoT technology to bring automotive-related activities under real-time surveillance. It will aid in the reduction of maintenance and operation expenses, the improvement of productivity, the assurance of security and organizational transparency, the comfort and safety of pedestrians and vehicle users, and many other good aspects. Here the authors have presented an implementation approach that, as shown in Figure 3, holistically assesses the ASC operations as part of the ReSOLVE model utilizing IoT. The Delphi method will be used to evaluate this framework.

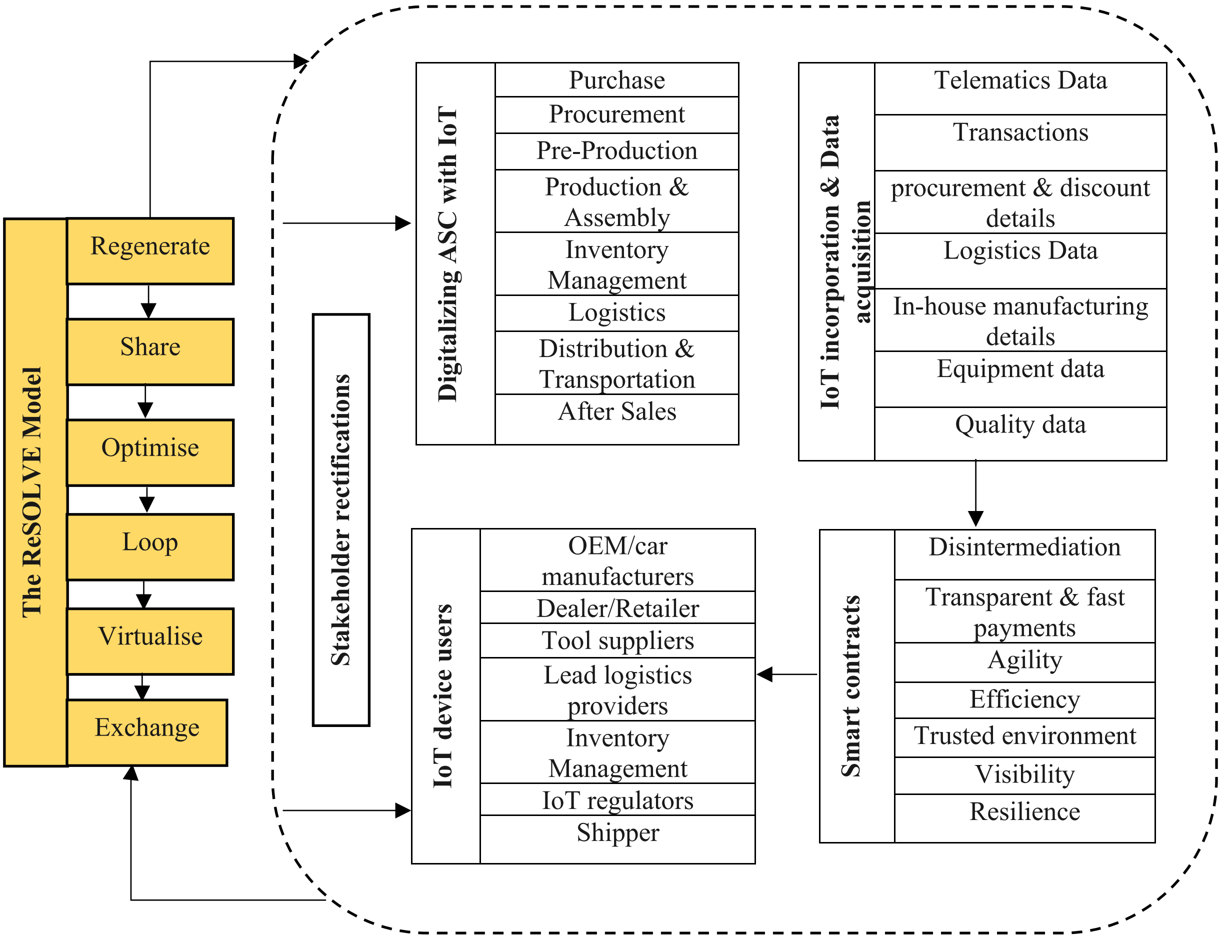

Figure 3. Proposed Framework (Source: Created by authors)

4. Framework validation

The Delphi method involves asking numerous rounds of questions and letting the panel know what the community as a whole believes to arrive at the correct answer by consensus. Consensus can be reached over time as views become persuaded, making the procedure very successful. Therefore, this research has used a two-round Delphi study, and the findings of both rounds are given further. The experts' responses from rounds 1 & 2 Delphi study are presented in Tables 3 and 4.

4.1 Delphi study round 1

In the first round, replies to the present criteria were analysed to ascertain consensus. It is widely believed that the essence of the Delphi technique is consensus building. In contrast to questionnaire surveys, which ask for non-experts' opinions on a subject, the Delphi technique aims to determine the view of experts on the subject related to the automotive supply chain, IoT, and sustainability. The Delphi study must therefore ensure that all of the questions are agreed upon. In Delphi Studies, a consensus is hard to quantify. The literature has shown that there is no agreement on how to assess agreement among a group of viewpoints, as was stated above. According to (Holey et al., 2007), consensus could be established by the subsequent methods: the sum of evaluations, a shift to a perceived degree of a normal distribution or, alternately, by proving consistency in responses throughout study rounds to show steadiness in answers.

For round 1, the study found a lower score for three factors, which are Shippers (65.40%), Inventory management (71.89%), and Resilience (65.40%) - as shown in Table 3. The scores of these three factors are less than 75%, which is the minimum acceptable rate for this study. It means the experts do not have a mutual consensus on these three factors which leads to removing three factors from the framework.

4.2 Delphi study round 2

The second round of the study was intended to allow experts to examine and discuss the agents that makeup stakeholders' rectifications as well as other concerns regarding potential risks that may emerge during the integration process, which were proposed by the experts in Round One.

In the second round Delphi study, we have removed these three factors — Shippers, Inventory management, and Resilience — from the framework, which leads to considering 26 final factors out of the 29 original factors. Also, in round 2, the study found a lower score for the factor “Pre-production” which is 75%. This study's lowest score is greater than the minimum acceptable rate (75%) as shown in Table 4. It means the experts have a mutual consensus on all the factors and leads to no factor to remove from the framework. One more interesting thing was found after the two-round Delphi study. The overall consensus for each “Stakeholders Rectifications” was improved in the first round. This means that the experts mutually agree with the second amendment. Therefore, after these two-round Delphi studies, the framework was finalized and validated.

Table 3. Experts' responses in Delphi study Round 1 (Source: Created by authors)

Round 1										
Groups of factors under The ReSOLVE Model			**No. of Responses for each factor**					**Consensus calculation in percentage (%)**	**Individual Consensus (%)**	**Overall Consensus (%)**
S.No.	**Stakeholders Rectifications**	**Related components**	**Strongly Disagree (1)**	**Disagree (2)**	**Neither Disagree nor Agree (3)**	**Agree (4)**	**Strongly Agree (5)**			
1	IoT Device Users	OEM/ Car Manufacturers	3	2	8	8	16	[{((1*3+2*2+3*8+4*8+5*16)/37)/5}*100]	77.29%	78.30%
		Dealer/ Retailer	4	1	5	9	18	[{((1*4+2*1+3*5+4*9+5*18)/37)/5}*100]	79.46%	
		Tool suppliers	3	3	7	9	15	[{((1*4+2*1+3*5+4*9+5*18)/37)/5}*100]	76.21%	
		Lead logistics provider	1	1	3	11	21	[{((1*4+2*1+3*3+4*11+5*21)/37)/5}*100]	87.02%	
		Inventory management	2	2	4	7	22	[{((1*2+2*2+3*4+4*7+5*22)/37)/5}*100]	84.32%	
		IoT regulators	5	0	3	14	15	[{((1*5+2*0+3*3+4*14+5*15)/37)/5}*100]	78.38%	
		Shippers	4	5	5	10	13	[{((1*4+2*5+3*5+4*10+5*13)/37)/5}*100]	65.40%	
2	Digitalizing ASC's with IoT	Purchase	0	1	3	12	21	[{((1*0+2*1+3*3+4*12+5*21)/37)/5}*100]	87.02%	80.27%
		Procurement	3	3	4	7	20	[{((1*3+2*3+3*4+4*7+5*20)/37)/5}*100]	80.54%	
		Pre-production	1	4	2	4	26	[{((1*1+2*4+3*2+4*4+5*26)/37)/5}*100]	87.02%	
		Production Inventory	4	3	2	6	22	[{((1*4+2*3+3*2+4*6+5*22)/37)/5}*100]	81.08%	
		Inventory management	5	5	4	9	14	[{((1*5+2*5+3*4+4*9+5*14)/37)/5}*100]	71.89%	
		Logistics	2	2	5	10	18	[{((1*4+2*1+3*5+4*9+5*18)/37)/5}*100]	81.62%	
		Distribution & Transportation	3	4	3	14	13	[{((1*3+2*4+3*3+4*14+5*13)/37)/5}*100]	76.21%	
		After Sales	4	1	8	8	16	[{((1*4+2*1+3*8+4*8+5*16)/37)/5}*100]	76.75%	
3	IoT incorporation	Telematics Data	0	3	4	10	20	[{((1*0+2*3+3*4+4*1	85.40%	80.58%

	& Data acquisition							0+5*20)/37)/5}*100]		
		Transactions	1	2	7	14	13	[{((1*1+2*2+3*7+4*14+5*13)/37)/5}*100]	79.46%	
		Procurement & discount details	5	0	3	11	18	[{((1*4+2*1+3*5+4*9+5*18)/37)/5}*100]	76.52%	
		Logistics data	3	3	3	8	20	[{((1*3+2*3+3*3+4*8+5*20)/37)/5}*100]	81.08%	
		In-house manufacturing details	4	1	6	11	15	[{((1*4+2*1+3*6+4*11+5*15)/37)/5}*100]	77.29%	
		Equipment data	2	1	4	6	24	[{((1*4+2*1+3*4+4*6+5*24)/37)/5}*100]	86.49%	
		Quality data	3	4	2	13	15	[{((1*3+2*4+3*2+4*13+5*15)/37)/5}*100]	77.84%	
4	Smart Contracts	Disintermediation	3	0	0	10	24	[{((1*3+2*0+3*0+4*10+5*24)/37)/5}*100]	88.10%	79.68%
		Transparent & Fast payments	0	0	4	15	18	[{((1*0+2*0+3*4+4*15+5*18)/37)/5}*100]	87.57%	
		Agility	2	5	4	5	21	[{((1*2+2*5+3*4+4*5+5*21)/37)/5}*100]	80.54%	
		Efficiency	4	2	2	15	14	[{((1*4+2*2+3*2+4*15+5*14)/37)/5}*100]	77.84%	
		Trusted environments	3	5	1	9	19	[{((1*3+2*5+3*1+4*9+5*19)/37)/5}*100]	79.46%	
		Visibility	4	1	5	10	17	[{((1*4+2*1+3*5+4*10+5*17)/37)/5}*100]	78.91%	
		Resilience	7	6	5	8	11	[{((1*7+2*6+3*5+4*8+5*11)/37)/5}*100]	65.40%	

Table 4. Experts' responses in Delphi study Round 2 (Source: Created by authors)

Round 2										
Groups of factors under The ReSOLVE Model			**No. of Responses for each factor**					**Consensus calculation in percentage (%)**	**Individual Consensus (%)**	**Overall Consensus (%)**
S. No.	**Stakeholders Rectifications**	**Related components**	**Strongly Disagree (1)**	**Disagree (2)**	**Neither Disagree nor Agree (3)**	**Agree (4)**	**Strongly Agree (5)**			
1	IoT Device Users	OEM/ Car Manufacturers	3	2	2	5	20	[{((1*3+2*2+3*2+4*5+5*20)/32)/5}*100]	83.12%	81.76%
		Dealer/ Retailer	4	3	0	10	15	[{((1*4+2*3+3*0+4*10+5*15)/32)/5}*100]	78.12%	
		Tool suppliers	1	4	2	9	16	[{((1*1+2*4+3*2+4*9+5*16)/32)/5}*100]	81.88%	
		Lead logistics provider	2	2	1	11	16	[{((1*2+2*2+3*1+4*11+5*16)/32)/5}*100]	83.12%	
		Inventory management	1	1	3	15	12	[{((1*1+2*1+3*3+4*15+5*12)/32)/5}*100]	82.50%	
		IoT regulators	3	1	2	10	16	[{((1*3+2*1+3*2+4*10+5*16)/32)/5}*100]	81.87%	
2	Digitalizing ASC's with IoT	Purchase	4	0	0	13	15	[{((1*4+2*0+3*0+4*13+5*15)/32)/5}*100]	87.02%	81.44%
		Procurement	1	3	3	7	18	[{((1*1+2*3+3*3+4*7+5*18)/32)/5}*100]	83.75%	
		Pre-production	5	2	0	14	11	[{((1*5+2*2+3*0+4*14+5*11)/32)/5}*100]	75%	
		Production Inventory	2	1	3	7	19	[{((1*2+2*1+3*3+4*7+5*19)/32)/5}*100]	85%	
		Logistics	3	3	0	6	20	[{((1*3+2*3+3*0+4*6+5*20)/32)/5}*100]	83.12%	
		Distribution & Transportation	2	2	4	13	11	[{((1*2+2*2+3*4+4*13+5*11)/32)/5}*100]	76.87%	
		After Sales	3	0	5	11	13	[{((1*3+2*0+3*5+4*11+5*13)/32)/5}*100]	79.37%	
3	IoT incorporation & Data acquisition	Telematics Data	2	4	0	8	18	[{((1*2+2*4+3*0+4*8+5*18)/32)/5}*100]	82.50%	84.01%
		Transactions	1	1	1	11	18	[{((1*1+2*1+3*1+4*11+5*18)/32)/5}*100]	87.50%	
		Procurement & discount details	2	1	4	8	17	[{((1*2+2*1+3*4+4*8+5*17)/32)/5}*100]	83.12%	

		Logistics data	3	2	1	7	19	[{((1*3+2*2+3*1+4*7+5*19)/32)/5}*100]	83.12%	
		In-house manufacturing details	2	2	4	8	16	[{((1*2+2*2+3*4+4*8+5*16)/32)/5}*100]	81.25%	
		Equipment data	3	1	3	10	15	[{((1*3+2*1+3*3+4*10+5*15)/32)/5}*100]	80.62%	
		Quality data	4	0	0	15	13	[{((1*4+2*0+3*0+4*15+5*13)/32)/5}*100]	90%	
4	Smart Contracts	Disintermediation	2	5	2	6	17	[{((1*2+2*5+3*2+4*6+5*17)/32)/5}*100]	79.37%	82.81%
		Transparent & Fast payments	0	0	5	15	12	[{((1*0+2*0+3*5+4*15+5*12)/32)/5}*100]	84.37%	
		Agility	4	1	0	6	21	[{((1*4+2*1+3*0+4*6+5*21)/32)/5}*100]	84.37%	
		Efficiency	1	0	1	13	17	[{((1*1+2*0+3*1+4*13+5*17)/32)/5}*100]	88.12%	
		Trusted environments	2	4	2	11	13	[{((1*2+2*4+3*2+4*11+5*13)/32)/5}*100]	78.12%	
		Visibility	1	3	3	9	16	[{((1*1+2*3+3*3+4*9+5*16)/32)/5}*100]	82.50%	

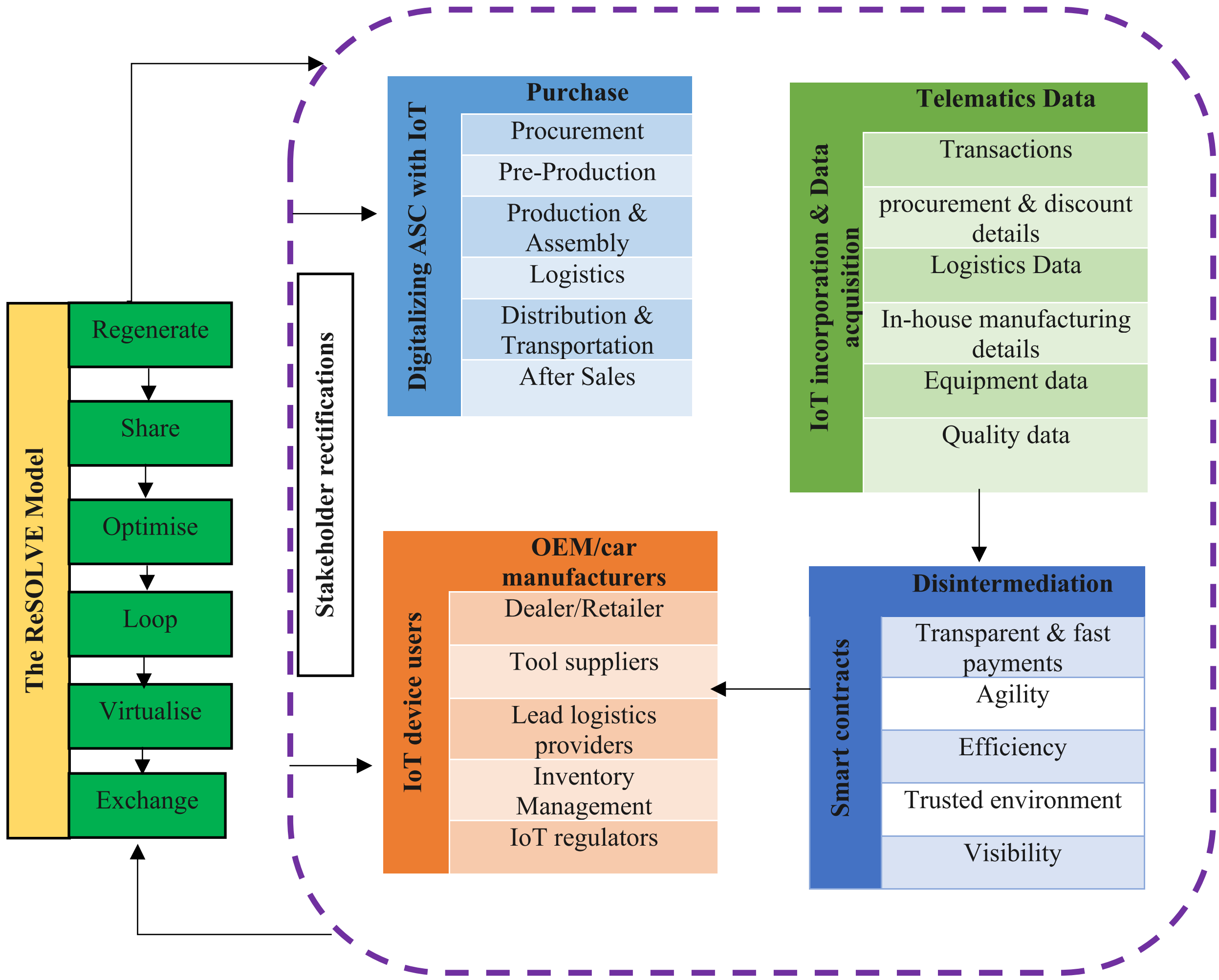

Figure 4. The final framework of IoT- SASC implementation (Source: Created by authors)

5. Discussion

The purpose of this study was to show how IoT tools have the potential to redesign conventional ASC into sustainable ASC. To shed light on SASC and IoT tools, an integrated IoT-sustainable ASC framework is proposed, and its deployment is examined to address three research questions: *RQ1: How does IoT adoption help achieve sustainable automotive supply chain practices (SASC)? RQ2: Why are IoT solutions essential to achieve sustainability in ASC? RQ3: How can IoT and sustainable development practices be combined to achieve an effective SASC for stakeholders?*

Given that only a very small number of prior works have proposed and implemented IoT-enabled solutions for SASC, our study adds to the literature on SSCM and IoT by combining the ReSOLVE model and the Delphi approach to provide a probable course of action and ranking any hazards that might develop over this accession process.

In the study described in this paper, the Delphi method served as the initial step of the study to provide a conceptual framework for integrating IoT technology into a SASC, outlining potential actions, and ranking potential risks that might materialize during the integration process. The Delphi method was discovered to be a priceless tool for validating the information provided in the literature when developing a theory. Furthermore, it was determined to be a crucial step in carrying out a thorough examination of human settlement psychosomatic difficulties. However, carrying out a Delphi survey necessitates careful management of both the panellists and the data that has been gathered. 29 factors that constitute the stakeholders' rectifications are presented in the study's questionnaire's four sections (stakeholders' rectifications). To help the experts comprehend the study more thoroughly, the conceptual framework was presented to them (see Appendix A). 78 experts were chosen for the study and emailed. 37 experts out of 78 agreed to take part in this study. The questionnaire's validity was tested in a pilot study with 15 people who had no prior knowledge of the ASC, the IoT, and sustainability. The conceptual framework is validated using a two-round Delphi study. Every expert was interviewed in the preliminary round. In this session, the framework's parts were the subject of qualitative feedback requests from the experts. They were likewise asked to offer success characteristics and IoT and SASC implementation efforts. Three factors - Shippers (65.40%), Inventory management (71.89%), and Resilience (65.40%)—had lower scores in the first round. These three criteria' scores are below the minimum allowed level for this study, which is 75%. This indicates that the experts do not agree on these three variables, which results in the removal of three factors from the framework. Due to the removal of these three factors from the framework in the second round of the Delphi technique, only 26 final factors—out of the initial 29—were taken into consideration. A lower score of 75% was observed for the factor "Pre-production" in round 2 of the investigation. The lowest score in this study is higher than the required minimum (75%). In this context, the results obtained indicate that all of the experts agree on all the factors, which prevents any factors from being eliminated from the framework. In the wake of the two-round Delphi study, another intriguing finding was made. In comparison to the initial round, the overall consensus for each "Stakeholders Rectification" was better. This indicates that more experts agree on the second amendment. The framework was therefore completed and validated following these two rounds of Delphi studies.

In order to respond to the first research question, this study provided a high-level architecture of the suggested IoT-enabled solution by outlining the various elements used for the SASC. The final 26 factors - stakeholder rectifications - can be used by businesses in the automotive sector or other sectors to adopt IoT tools for SSCM at a firm level (see Appendix A). Businesses that wish to adopt IoT tools for SASC at a supply chain level can do so by utilizing the proposed framework which provides automated negotiations between OEMs and purchasing stakeholders. According to (Manavalan and Jayakrishna's study, sharing real-time data can facilitate cooperation between supply chain partners like manufacturers, vendors, retailers, and customers in IoT environments, which has advantages for the entire supply chain. In line with (Manavalan and Jayakrishna, 2019), the suggested framework (see Figure 4) offers a system for continuous tracking that has been designed and verified to offer practitioners an improved grasp of how to incorporate IoT technology into a SASC, specify suitable measures, and prioritize potential risks that may emerge.

The results of this study are in accordance with earlier research, which shows that IoT solutions support businesses in providing sustainable products (Yadav et al., 2020), and can be used to answer the second research question by drawing on the application of the suggested framework. According to (Turner et al., 2022), IoT tools can be used to create sustainable shipbuilding supply chains that enhance economic, energy, and environmental factors. This study, which focuses on the factors that promote sustainable development practices and sustainable supply chain management (RQ3), offers proof of advancements in all the stakeholders' rectifications. Accordingly, in order to take advantage of the synergies between SASC and IoT, SASC should be seen as a policy-driven integrated strategy that focuses on using IoT to reach long-term sustainability via resource efficiency and co-optimizing social value and business, thereby improving the environment, the economy, and society. More research should go into developing an implementation strategy for the IoT that takes into account the quintuple bottom line (social, environmental, economic, technological, and organizational) and the quintuple helix (government, industry, university, society, and environment).

5.1 Implications for practitioners

The current study significantly advances both theory and practice in the areas of ASC, sustainability, and IoT. The automobile industry's digital revolution will be fuelled by the demand for supply chains that are transparent, visible, traceable and effective. Professionals must assess their current position in the sector as rising technologies are affecting several operations. Professionals must be aware of the benefits and drawbacks of IoT in the SASC; before a corporation adopts an emerging technology, it is crucial to perform research to assess the level of complexity and additional benefits it will provide. Here, the primary objective is to demonstrate to practitioners the capabilities, range, and advantages of IoT in SASC and to identify the crucial areas that can be automated and enhanced by ASC performance. Additionally, RQ3 is addressed by creating the SASC implementation framework, which is depicted in Figure 4. Furthermore, the Delphi analysis reveals that IoT technology is not just restricted to the sectors mentioned below but can be applied to the majority of SASC components. The car industry's operations could be transformed into interoperable, intelligent entities due to IoT. The profitability and productivity of OEMs can be increased by the assessment of information obtained from facilities, production operations, and logistics. To improve their business processes, foster trust, and establish a specific objective truth, practitioners must invest in digital and new technology. IoT technology could be used in a broad range of applications across sectors. For instance, the automotive sector itself has potential applications outside of those covered here. For example, IoT technology can be employed in shared mobility ecosystems, smart auto maintenance programs, digitizing tollbooth activities (Mary Dayana and Sam Emmanuel, 2020), developing an IoT-based virtual model of a car, and tracking the life events of cars throughout their life cycle. Depending on each organization's vision and operational capabilities, IoT use scenarios may vary. Therefore, practitioners need to learn about the intricate difficulties that their companies are dealing with, determine if IoT technology could address those challenges, and determine whether they can integrate IoT into their networks. Practising professionals may engage in digital technology to enhance their current processes after they have a comprehensive understanding of the IoT potential in their ecosystem. Applications for machine learning also assist in the efficiency and productivity of supply chains that include IoT. Greater inbound/outbound logistics control, streamlined vehicle routing, effective facility use, predictive/preventive maintenance, and improved supplier activity monitoring are all potential benefits of this interaction. Digital technology also enables real-time monitoring and tracking, prompt product recalls due to flaws, the detection of fake parts, and regulatory activity monitoring. OEMs may develop data-driven smart supply chains and manufacturing processes by implementing digital technology.

5.2 Implications for theory

This research offers a number of theoretical contributions to the IoT and SASC paradigms. First, this research offers solid empirical proof regarding how the introduction of SSCM practices will support the advancement of SASC performance in terms of environmental, economic, and operational aspects. The majority of earlier studies (e.g., Ali et al., 2023; Mukherjee et al., 2023; Patil et al., 2023) focused on the effects and benefits of IoT in the manufacturing, agriculture/food, and service sectors. Other studies (e.g., (Ali et al., 2023a; Mirzabeiki et al., 2023) identified the drivers and barriers to SSCM implementation. Furthermore, few theoretical approaches have been developed in the literature that emphasize the incorporation of IoT tools and their relevance for sustainable supply chains (Ding et al., 2023; Mosallanezhad et al., 2023). This initial empirical investigation into the ASC illuminates the distinctive interactions between IoT and SSCM.

Moreover, our findings demonstrate the importance of stakeholders' integration into the ASC. Organizations implementing IoT in their pursuit of SSCM can benefit from the establishment and/or enhancement of suppliers and customer cooperation in the ASC (Rizvi et al., 2023). This result is consistent with earlier SSCM research. Indeed, a business could profit from IoT technology to strengthen its collaboration and SC reliability the more partners and stakeholders in the SC it can incorporate into its approach to sustainability. In this technological environment, transparency, openness, traceability, visibility, and reliability for all supply chain participants are feasible (Ding et al., 2023; Pouresmaieli et al., 2023). Furthermore, as an organization improves its capacity for achieving these objectives, it might also become more adaptable and open to environmental modifications that affect its SC. Besides, IoT enables businesses to launch new products more quickly and restructures sustainable supply chains in response to shifting stakeholder demands (Mosallanezhad et al., 2023). This is especially true given that the IoT can support more rapid storage, data collection, and management, promoting vital supply chain and product information (Ali et al., 2023b).

5.3 Managerial implications

This study provides managerial implications for the use of IoT technology for enhancing SASC in addition to theoretical and practical contributions. The primary target of this study, the automotive industry, is heavily investing in IoT tools. Both the items they promote and the things they use might be the subject of these efforts. The SASC can be efficiently supported by IoT tools. This paper's approach can help practitioners integrate IoT tools, especially considering their growing significance and connections to SASC. Our study offers preliminary direction for explicit SASC consideration using IoT tools. This advice and facilitation are new. It is challenging for practitioners to implement all I4.0 technologies concurrently in real-world IoT contexts. Therefore, managers will benefit from focusing on the finest IoT tools for them and their industry thanks to the set path and SASC linkage prioritization of IoT tools estimated in this study.

Although we take the priorities and importance of the entire sector into account, organizations may find that SASC impacts on achievement differ following the particulars of the industry or other factors. The automotive industry can be extremely diverse, with different-sized businesses that may exist at various points throughout the supply chain. For instance, some of these organizations may be in charge of the activities associated with the takeback and remanufacturing of automobiles. They might take into account various technological factors in this context than those that normal original equipment manufacturers would focus on when fabricating or assembling their products. Managers must therefore use caution when interpreting these findings, which could also serve as general advice on the relative significance and implications of SASC.

Government agencies and the major company players should develop regulations that support the implementation of IoT tools and sustainable business exercises in the ASC. To raise awareness, it ought to address how corporate culture is changing both internally and externally. Surveys must be conducted to evaluate individual awareness organizations. The go-ahead must be provided for stakeholders to concur with that viewpoint, and cooperation must be promoted. The government and businesses should also provide rewards and remuneration in their processes to encourage organizations to embrace these rules. Organizations must exert pressure on the government to supply funding and stimulants for the development of more environmentally friendly products and the maintenance of sustainable practices. Additionally, it is advised that an organization look into any employee conduct that can affect how things are done because of apprehension about cultural change. It is advised that both public and private businesses run awareness campaigns to educate both their staff and customers to improve the sustainability and operational effectiveness of IoT tools. These initiatives will improve communication between businesses and consumers and motivate both to create sustainable systems.

6. Conclusions

The study fills a gap in the literature by offering helpful details on examining the potential of IoT in SASC. In line with the research objective, the present study provides an exhaustive IoT-SASC framework to provide answers to the research questions. Using a combination of the ReSOLVE model and the Delphi technique, this study examined the researchers' experience implementing IoT technology into a SASC. Out of 78 experts who were asked to take part in the study, 32 specialists ultimately finished it, proving that the criteria established for finding the experts for the study were successful. Despite its difficulties and time-consuming nature, the Delphi method was successful because the experts promptly provided their thoughts. The Delphi findings were stable after two rounds, and the framework was finished and validated. The study significantly fills the research gaps found in the literature by offering helpful details on examining the potential for IoT in the SASC. The criteria established for attaining consensus using a variety of factors were also discovered to be important because merely one or two components could be incorrect and produce incorrect findings. The high consensus rate for the study, given that it used two sequential rounds of Delphi, further demonstrates the success of the experts' selection and the topic of debate.

Large amounts of data that are accurate and timely can be gathered with IoT technology in the SASC, enabling earlier detection of deviations. The accessibility of data regarding the precise position, or condition of the goods or ecosystem facilitates the capacity to recognize the nature of potential issues and take the necessary steps. By setting up early alerts on system irregularities that show up, for example, as delays in the Estimated Time of Arrival (ETA), it is possible to react more rapidly. Historical data from the IoT system can be saved and examined to assist in identifying problems, enhance performance, and create more accurate future projections. The study also covered the consequences for managers, researchers, and practitioners. Despite the fact that this study has provided managerial implications for businesses, there are a number of specific limitations that point to potential areas for future research. First, one of this study's shortcomings is the small size of the expert panel that took part in it. According to (Skulmoski et al., 2007), larger sample sizes might result in more conclusive findings. Future research could examine the framework and solution in larger supply chains and in other industries globally to enable the generalization of the findings. The validation process is still in progress; hence the final framework needs to be field-tested. Therefore, to improve it, the final framework will be assessed and applied in real workplace settings in subsequent research.

The automotive sector is a field that is hugely shaped and impacted by its stakeholders (e.g., governments, investors, consumers, employees, rivals) demands. Our study highlights that one of the less explored topics in the literature is examining the requirements of the stakeholders. In particular, the study found that a small number of studies that have been published in this literature have mainly concentrated on the impact of stakeholder pressure on a single company's growth or adoption of environmental strategies. The automotive industry has a multi-tiered, complicated supply chain network where environmental degradation occurs most frequently. Future research should focus on the potential impact of stakeholder demands on the way the automotive industry's supply chain tiers cooperate to deal with the pressure.

Regarding the pressure from stakeholders, future research must keep up with the sector's rapid expansion and shifting expectations. The automotive industry is under increased pressure to make sure that the stakeholders' sustainable requirements are fulfilled as a result of the worldwide increase in the production of automobiles, and the industry's globalization. By 2050, for example, the industry plans to achieve clean cities and zero emissions by using renewable sources of electricity and alternative energies [1]. In this context, it is critical for the automotive sector to effectively address the intricate and evolving requirements of its stakeholders. More scholarly investigation is needed to aid the industry in addressing this issue. For instance, determining the most important stakeholders and looking into how their requirements and demands have changed as technology has advanced can be an intriguing field of study. Further, as technology advances, it becomes more difficult to strike the right balance between the industry's financial gain and stakeholder expectations for environmental sustainability. These are some of the main issues that provide plenty of room for further research.

Despite the increasing amount of literature on organizational performance, little attempt has been made to address the invisible values that could be generated by sustainability-conscious practices in the automotive industry. Understanding the relationship between SSCM implementation and organizational performance would be improved by researching the latent

[1] https://www.un.org/en/climatechange/raising-ambition/renewable-energy

costs or intangible values of SSCM procedures, which could promote the proactive embrace of SSCM practices outside of the legal framework. Despite the strategic significance of management skills for creating an SSCM, this topic is seen as understudied. Although it has been previously extensively covered in the literature on traditional supply chain management, the significance of managerial skills such as cooperation and relationship management, information management, human resource management in the supply chain, and knowledge and risk management could be another interesting issue for future research.

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Appendix A

This paper aims to offer a conceptual framework for integrating IoT technology into a sustainable automotive supply chain, identify potential courses of action and rank potential dangers that may emerge during the incorporation process, using a combination of the ReSOLVE model and the Delphi technique. Table A1 is about the stakeholders' rectification and related factors which are considered in the supposed framework depicted in Figure A1.

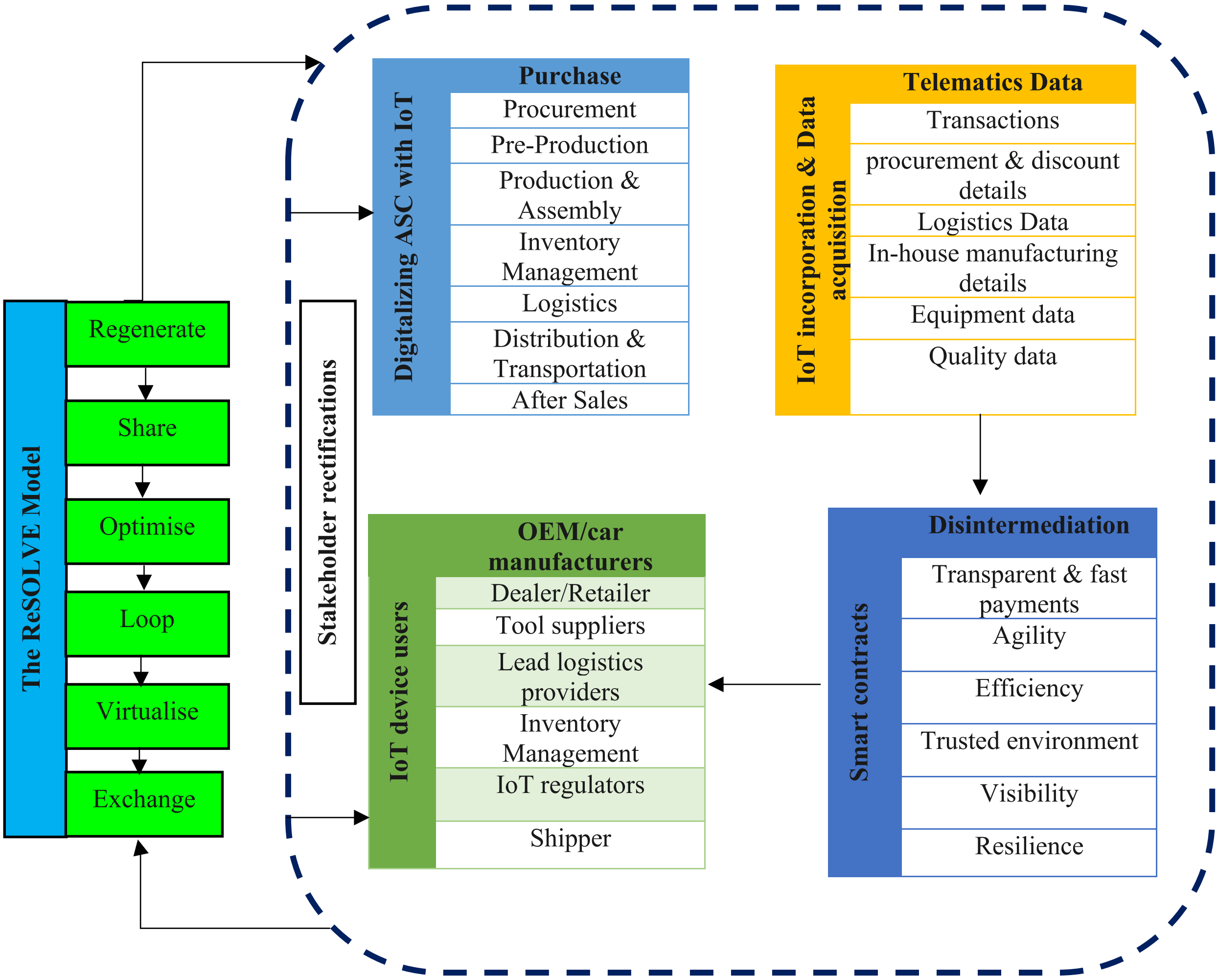

Figure A1. Proposed Framework.

Table A1 - Stakeholders' rectifications and related factors.

S. No.	Stakeholders Rectifications	Related factors	Brief description
1	IoT Device Users	OEM/ Car Manufacturers	transforming production facilities into IoT-connected ecosystems to boost output, minimize costs, and improve product quality
		Dealer/ Retailer	IoT is used by retailers for consumer engagement, hardware management, inventory management, and tracking of various goods and services.
		Tool suppliers	Know more specifically how the goods are stored, where they are located, and when to expect or pick them up.
		Lead logistics provider	Facilitate the management of stock levels, the storage of items, and the provision of fleet management services.
		Inventory management	Providing timely updates on the goods' condition, whereabouts, and movement
		IoT regulators	generate a variety of advantages for consumers and ASC in terms of safety and efficiency
		Shippers	The manufacturing facility's raw supplies, and Monitor resources and supply levels in the manufacturing or warehouse.
2	Digitalizing ASC's with IoT	Purchase	Enables online ASC to monitor customer orders from the time they are placed until they are delivered to their doorsteps.
		Procurement	Provide the ability to send data without the necessity for direct human or computer interaction.
		Pre-production	help ASC cut operating expenses and boost productivity throughout the whole production process
		Production Inventory	Provide real-time data gathered from RFID tags to provide constant visibility into the inventory.
		Inventory management	Collect data, control the flow of items, and make it simple for ASC to keep track of an item's specific position.
		Logistics	Enables the integration of different assets inside the ASC and the analysis of the data produced by these connections.
		Distribution & Transportation	the data is collected and transmitted over specialized software To convert the facts about the real-world event into valuable information
		After Sales	Prevents expensive repair visits and frustrating equipment breakdowns before they occur.
3	IoT incorporation &	Telematics Data	increases the capacity of fleet managers to Keep track of drivers, vehicle usage, and maintenance requirements

	Data acquisition	Transactions	increases data analysis frequency and permits performance enhancements
		Procurement & discount details	Improves equipment and supply utilization for procurement and discount information and increases spend visibility.
		Logistics data	boosting ASC output while cutting expenses and mistakes
		In-house manufacturing details	Enables car manufacturers to use data more effectively and tighter system integration to obtain more visibility and insights into their operations.
		Equipment data	helps vehicle manufacturers improve and optimize their processes through precise data extraction
		Quality data	Real-time data generation increases operational reporting and has higher accuracy and reliability.
4	Smart Contracts	Disintermediati on	preventing human error and ensuring the production of trustworthy documentary evidence
		Transparent & Fast payments	assist in enhancing communication between parties, increasing speed and efficiency, and the average ASC
		Agility	Using actual real-time data insights, eliminate supply chain blind spots and increase the agility and resilience of ASC.
		Efficiency	Provides stakeholders with real-time data on each asset's position and status, bringing transparency and accuracy to the entire ASC.
		Trusted environments	reduce waste with smart devices and management systems that assist in product recovery, restoration, and recycling and minimize trash
		Visibility	permits the parties to exchange crucial real-time information, minimizing disturbance
		Resilience	Brings decision-making closer to the action, making it simpler to reach quick, precise, fact-based conclusions.