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Shaping The Future Of Large-Scale Vehicle Manufacturing: Planet 2050 Initiatives And The Role Of Predictive Analytics

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This paper outlines the Planet 2050 initiatives currently planned at the International Center for Advanced High-Speed Vehicle Manufacturing in the areas of high-speed manufacturing equipment development, workforce training, advanced high-speed vehicle design and manufacturing, and integrated sets of manufacturing infrastructure products. It then addresses the intersection of advanced vehicle design and manufacturing with the use of predictive manufacturing analytics as a key technology enabler for the development of new vehicle manufacturing concepts aimed at significantly reducing labor costs, reducing energy costs, increasing overall factory operational effectiveness, and increasing competitiveness of the United States and other high-cost manufacturing countries. The ongoing work at the SAMPL Industry and Science Partnership Center at various universities is presented, and key needs for the sustained U.S. and global competitiveness of automotive and vehicle manufacturing are highlighted. Application of the larger physics insights in each of the four roadmap technology areas of industry, software, facilities, and workforce will enable the United States to develop new high-value factories producing high-value, energy-efficient cars, and mass transit vehicles that are the cars of the future in U.S. or global automotive marketplaces.

Keywords: Planet 2050, High-speed manufacturing, Advanced vehicle design, Predictive manufacturing analytics, Operational effectiveness, Labor cost reduction, Energy-efficient vehicles, Manufacturing infrastructure, Global competitiveness, Workforce training

1. Introduction

The automotive industry is experiencing a change much more fundamental than moving to electric powertrains: in the medium term, how vehicles are designed, and manufactured, and many of the business models currently in place may have to revert to 'the drawing board.' This paper applies the concept of 'deep uncertainty' from the field of Decision Making Under Uncertainty to the future of large-scale automotive manufacturing. Namely, deep uncertainty is characterized by both a lack of precise knowledge of which theoretical systems are operative in a given case and a lack of agreement on the range of outcomes over a given long-term horizon of analysis. It posits the acceptance and exploration of a wide range of scenarios of future states, or 'worldviews' as many different actors may operationalize these states differently.

To explore the key sources of deep uncertainty facing long-term automotive vehicle manufacturing, the six focus areas introduced to the conferences: Mobility-as-a-Service, Product (vehicle) data platforms, Digital Twins, Explore-Print-Test, Factory 2025, and Artificial Intelligence/Data led were adopted. For each of these represent the current 'edge of the envelope' of research thinking, a brief review is provided of the key technologies that could potentially make a material difference. Then, drawing from long-term written evidence and using both deep-uncertainty-specific tools and more 'traditional' strategic analysis tools, a selection of scenarios are developed and their implications for the role that key enablers play in shaping the future of vehicle manufacturing are discussed.

1.1. Background and Significance

The automotive industry is a powerful mover of national and regional economies, generating trillions of dollars in revenue every year. In this environment, transportation technology research has been understood to support innovation, enhance mobility, and address problems related to safety, protection of the environment, and energy sustainability in manufacturing. The ecosystem from which new vehicles emerge is vast, highly complex, and deeply interconnected at a global scale, as it consists of a myriad of partners from defense, academia, supply chain, logistics, and other areas. It is driven by signals from the market, federal regulations, and requirements on affordability, timeliness, customization, and, more recently and even stronger, on the longevity of performance and the ability to adapt to evolving relationships among users, inventions, and social values. The latter is particularly interesting, as analysts stress the fact that data-centric technologies, such as predictive analytics, are promoting the advent of new generations of smarter and more autonomous vehicles, which are in turn enabling changes in personal and big data relationships, typically known as the fourth industrial revolution.

When considering how the industry should work to generate safer, greener, flexibly applicable, and mass-produced intelligent vehicles, the Department of Defense initiated a study to investigate the future of large-scale vehicle manufacturing to identify potential innovative solutions that would have the most significant impact on the development of the next generation of strategic capabilities. These exploratory ideas form the basis of the invited talks, panel discussions, and interactions among researchers and industry counterparts who participated in a World Congress of the Society of Engineering Science. The event worked as preliminary feedback and validation of the Department’s technical expectations towards conventional and non-conventional industries interested in entering into visionary strategic partnerships aimed at the future of large-scale vehicle manufacturing.

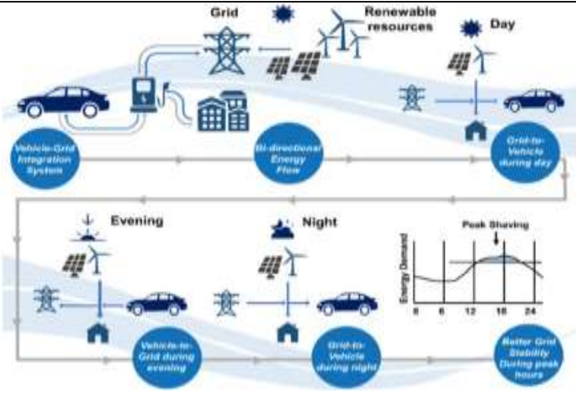

Fig 1 : An Illustration of the V2G Concept During Different Times of the Day

1.2. Research Objectives

The research objectives of this chapter are to: 1. Understand the current dynamics, challenges, and risk factors driving large-scale vehicle production and mass customization. 2. Present critical aspects, practical implications, and future opportunities of discrete forecasting and discrete demand model selection for the vehicle build-to-order system using predictive analytics. 3. Propose a predictive analytics framework for cost-sensitive demand forecasting and budget allocation optimization to customize the vehicle production system for demand implied by a specific strategy to match future market signals. 4. Analyze data that justifies formulating predictive analytics models for the following supply chain and predictability indicators: strategic drivers and market and production dynamics, with influence; relevant suppliers and manufacturers' current approaches to making forecasting and demand model selection decisions; common practices for demand forecasting and demand model selection; and advanced predictive analytics solutions for discrete forecasting and demand model selection within vehicle-related industries.

Equation 1 : Supply Chain Optimization

To model the efficiency of the supply chain, we can use the following equation:

$$C = \sum_{i=1}^{n} (C_i \times Q_i)$$

Where: C = Total cost of the supply chain

Ci = Cost per unit of resource i

Qi = Quantity of resource i

n = Total number of resources

2. Evolution of Large-Scale Vehicle Manufacturing

Large-scale vehicle manufacturing has always shaped society and has been highly responsive to society's needs. One of the first recorded orders for mass-produced motor vehicles was from a life insurance company. In 1900, a large order for a fleet of model cars was received, even as technology for the mass electrical distribution of power had yet to be fully developed. Gas stations were primitive, and road systems were in relative infancy. By 1918, production of the Model T had ceased with 15 million copies produced in some 20 years – the most stark and overt expression of the industry's ability to focus and advance until societal need had been served, which in such cases became the practical symbol of society. The beginning of the 20th century also saw the early development of larger, heavier trucks and buses, as well as off-road models which would develop several decades later into a defining characteristic of the industry: the transition between passenger cars and heavy-duty vehicles. Transition is again the operative word, not because the world stood still for a hundred years, nor even for the fifty years that followed. Nor could the world stand still in a period of the past fifty years which has seen unprecedented growth in status and influence of companies.

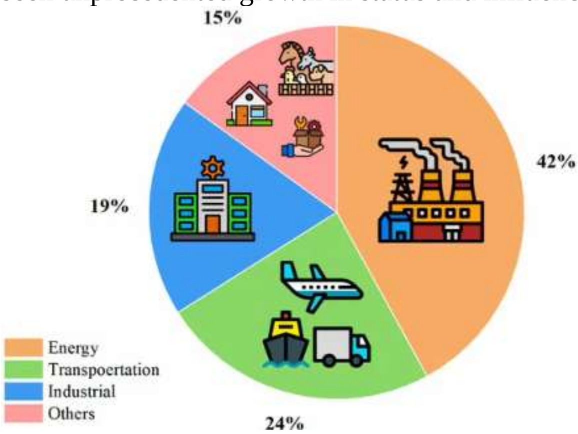

Fig 2 : CO2 emissions by sectors

2.1. Historical Overview

The Trends and Paradigms subproject contributes to the research of vehicle development and industrial production technology with a focus on the trends that will shape the automotive industry and its products within the next decades. Starting from a historical overview, the subproject focuses on the identification of the most significant and influential trends of each decade that will shape the vehicle on the edge of the reference year 2050. These trends are derived from different focus areas such as society, legislation, environment, and economy, but also customer lifestyles and urban environments, since especially there are some prominent driving forces. These trends are therefore constantly re-evaluated and ranked to derive major implications and to encourage initiating committed actions.

Most of this chapter will give a concise overview of the most important trends of the past 150 years that had an impact on the product 'vehicle'. A thorough analysis has been made, based on various literature and discussions with automotive experts from academia, suppliers, and manufacturers. The entire sequence of trends is embedded into a mankind stratification, splitting the vehicle history off from and re-coining it with societal and economic events.

Afterward, the trends' descriptions are delivered with detailed time stamps and finally, a proposal for the most prestigious trends frames the view of Planet 2050's vehicle.

2.2. Current Challenges

Current Challenges. Post-COVID-19, auto OEMs across the globe have initiated waves of staff reductions, temporary plant closures, coding strategies, canceling, and postponing new vehicle programs, and temporary payment cuts for white- and blue-collar workers, disrupting the pipeline of components and parts. Going forward, large-scale firms in the auto manufacturing industry need to continue their transformation journey and reinvent themselves while navigating through unprecedentedly complex and ever-increasingly challenging dynamics: sustainable growth, market globalization, shifting customer needs and perceptions, diversification, regionalization of ecosystems, a constant stream of new technologies, competitive innovation pressure, advances in predictive analytics and data management, the survival of the fittest business model, and sharing inspiring future representations. Across their entire product and process spectrum, the convergence of near- and long-term deeply transforming regulatory, behavioral, technological, strategic, corporate responsibility, collaborative, and trade dynamics progressively feeds this sense of urgency.

3. Planet 2050 Initiatives in the Automotive Industry

In the automotive industry, we can also find ambitious initiatives built on the minimization or elimination of emissions, reduction in the energy intensity of vehicles, and the priority of renewable energy sources. Two major visionary initiatives in the automotive industry are a project to produce zero-emission cars and the introduction of the fuel-cell hybrid bus. A project focused on the design studies of an ultra-low emissions vehicle resulted in the development of a new vehicle.

It aims to reduce fuel consumption to 1.3 l/100 km, using hydrogen storage technologies embedded in the vehicle and has achieved a reduction in vehicle weight by 47%. All vehicle technologies, such as passive safety, recycling, and electric vehicle technology, are examined and integrated for this proposal. Its purpose is the commercial development and deployment of technology for producing lightweight, full-sized cars that are safe, fuel-efficient, and inexpensive compared to the present automobile industry, particularly in reducing the cost of competition. Unlike existing cars, this vehicle will use less petroleum and contribute to moving toward a hydrogen-fuel economy. It should be commercially viable by 2010 at the latest. The future automotive industry could also become a hydrogen production and distribution company. The design is revolutionizing the automotive industry and related industries by developing new crack-resistant, shear-stiffened, honeycomb, and sandwich composite materials suitable for mass production at competitive stamping costs.

Fig 3 : Global Green Automotive Mobility Market Snapshot, 2018 to 2030

3.1. Sustainability Goals and Targets

For its 2050 goals, Forest City Technologies joined an industry collaboration of automotive, technology, and consulting organizations. The organization focuses on accelerating industry-wide innovation and progress toward achieving the ultimate goal of vehicle manufacturing – safe, comfortable, and private driving with minimum environmental impact. Specifically, the aspirations include contributing to the UN Sustainable Development Goals, particularly no poverty, good health, and well-being, quality education, gender equality, clean water and sanitation, industry, innovation and infrastructure, reduced inequalities, sustainable cities and communities, responsible consumption and production, climate action, life on land, and partnerships for the goals, as the wide-reaching sustainability milestones. To contribute to the goals, the increase in the durability of each vehicle, its lower emissions, and greater use of recycled materials are among the numerous activities that relate to the collaboration.

Through its relationship with the organization, Forest City Technologies, along with its member OEM and tiered partners, has set a variety of 2030 and 2050 greenhouse gas emissions and energy-related stretching goals for the industry, making the maximum use of energy from renewable sources and vehicle manufacturing, and improving the absolute energy efficiency and water use respectively. These quantities are calculated using 2019 data as a reference. In addition, the production of vehicles with a recyclability rate of 95%, with a recycled content of an average of 35%, shall be significantly expanded by 2030. The pre-2025 programs are particularly aimed at forming a shared perspective on recycling. For example, with 5% of post-consumer recycled resin used in 2022 projects, FPE enables customers to meet their sustainability goals – a customer request could therefore speed up the introduction of new materials with higher recycled resin percentages.

3.2. Technological Innovations

In Planet 2050, industry, academia, and government are cooperating to undertake a variety of research direction initiatives to push Japan's large-scale vehicle manufacturing sector up to a distinct new stage. An example of these initiatives is the e-Factory Promotion Linking with R&D, which is the initiative discussed in this chapter. In this initiative, we promote the "e-Factory for green innovation" via the specific top-priority themes on manufacturing technologies, develop their fundamental technologies and basic systems by integrating the advanced sensing systems, ICT, and network of manufacturing equipment, systems control, and realize the demonstration in a production setting, leading to social implementation. It was started in October 2008, with a period of 5 years. Volume production systems are fundamental to the mass customization production of high-quality, high-variety products and play key roles in the e-factory. The characteristics of semiconductors, FPD, and mechanical volumes such as automobiles, digital consumer products, and aircraft are different, but there are also commonalities such as the importance of aggregate systems. We have been conducting the e-Factory R&D for high-mix low-volume, high-difficulty products.

We work on model-based diagnostics and prognosis techniques for early detection of degradation and prediction of failure of multiple physical systems, such as processes, sensors, actuators, and machinery. The planned system is implemented on intelligent sensors and actuators equipped with miniaturized systems such as processors and MEMS-based actuators to ensure that developed techniques are suitable for the high-efficiency low-cost objective. Data-driven analysis technologies such as feature selection from multiple sources of sensory data streams, time-series modeling, information fusion, and others are also performed to enhance the system fault detection and diagnosis technologies. Maximum utilization of service experience and a grasp of equipment state based on equipment functions are key elements of system fault detection and diagnostics in the e-Factory.

Equation 2 : Predictive Maintenance

To predict maintenance needs and reduce downtime, we can use a reliability function:

$$R(t) = e^{-\lambda t}$$

Where: R(t) = Reliability function at time t

λ = Failure rate

t = Time

4. Predictive Analytics in Vehicle Manufacturing

With initiatives like Planet 2050 and the changing dynamics of large vehicle manufacturing, predictive analytics will play a significant role in shaping the future of vehicle manufacturing, helping manufacturers take a preventive approach, maximize their operational efficiency, and subsequently deliver better value to vehicle users and the environment. Predictive analytics enables businesses to predict their future behavior and gives them a strategic advantage. With the data-driven decision-making model and the use of a broad category of predictive models, vehicle manufacturers can predict the demand for their products, anticipate potential problems or faults in the manufacturing processes or the vehicle components' surfaces during the vehicle's lifetime, and predict business risks that may be harmful to their success. With these predictions, vehicle manufacturers can be prepared for potential opportunities or challenges, can be ready to cope with potential issues in time, and can reduce errors or further problems caused if business risks are not managed. In manufacturing processes, predictive models can be used to predict the quality of vehicle structures or the life cycle of vehicle components by analyzing data and finding latent relationships among existing vehicles' operational data and their dynamic attributes associated with the components' surface characteristics, life cycles, or operational circumstances. The latent relationships help identify the root cause of product defects and ensure reliable vehicle performance.

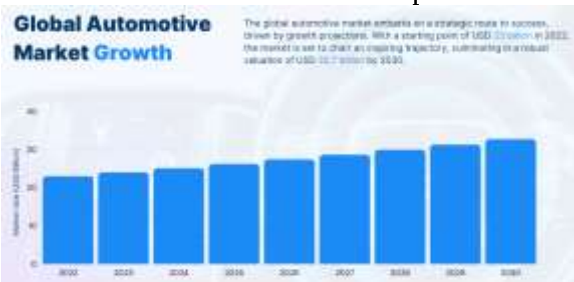

Fig 4 : Predictive Analytics in the Automotive Industry

4.1. Concepts and Applications

Articulated vehicle-based transportation systems are the main contributors to energy consumption and CO2 emissions in urban as well as intercity scenarios. They also contribute to environmental and social issues such as air quality problems, noise pollution, and accidents. Significant improvements can be achieved through better systems, and the long-term strategic goal of the identified industrial group is a reduction of absolute CO2 emissions by 40%, noting an expected increase in global freight traffic. The proposed solution to address these challenges is a breakthrough in automated, modular vehicle and transportation system operation capable of making both technology and operational infrastructure economically scalable. The landmark concept has been identified as a vehicle convoy of arbitrarily long length.
The performance assessment of future long multi-trailer vehicles is accomplished using load distribution diagrams based on nonsmooth steady-state response surfaces, given the need to account for snapping phenomena typical of such vehicles. A preliminary vehicle design tool has been developed to address shape optimization for a given set of mass distributions of payload and axial stiffness parameters of the suspension and steering systems, based on a topology optimization method. The developed scheme allows one to generate layout solutions that maximize the load transfer to the first two axles in quasi-static, steady-state conditions where the vehicle is not rotating around its main axis, and the load distributions are practically symmetric. The scheme allows one to guarantee stability compliance, showing a potential for producing iteratively optimized design solutions from the handling and performance perspectives.

4.2. Benefits and Challenges

By leveraging predictive analytics, Planet 2050's vision can extend several benefits not limited to enhanced resource planning, involving substantial improvements in the management of the workforce, raw materials, and the supply chain; enhancement of the product portfolio, with substantial improvements in the future of the product family, and detecting and intercepting changes in potential market trends earlier than expected; and more efficient and flexible production systems to comply with quick changes in products and adapt to the suggested multimodal transport system imposed by future mobility scenarios. However, the expected benefits are counterbalanced by a few challenges and threats. First of all, the unprecedented amount and variety of digital data collected by future factories create an immediate and widespread issue: cybersecurity, the new frontier of safety for modern factories. Then, unlike the classic enterprise systems providing feedback on current status and improving the predictive power of current systems, the deployment of predictive systems at the enterprise level should be able to select the right, future-oriented trends to pursue.

Due to these challenges, the adoption of predictive maintenance and other services within the premises of Planet 2050's companies will need to properly represent both the cultural and organizational backgrounds, suggesting the creation of an ad hoc accreditation of predictive analytics to apply it for the benefit of the new organization. In the short term, an important key element of future large-scale vehicle manufacturing systems is the necessity to pave the way for the introduction of organizational frameworks suitable for the integration of Industry 4.0 processes and the enhancement of enterprise resource plans coming from big data analysis. This in-depth paradigmatic change in modeling physical as well as organizational agent entities should be continued in the following years to meet the ever-increasing industrial roadmaps and, at the same time, present and validate a methodological approach that can be easily extended beyond the first manufacturing industrial applications of futuristic vehicles.

5. Integration of Predictive Analytics in Planet 2050 Initiatives

Integration of Predictive Analytics in Planet 2050 Initiatives. The application of predictive analytics in vehicle manufacturing has evolved into an advanced practice that goes beyond the mere application of statistical algorithms and utilizes advanced techniques from machine learning and artificial intelligence as well as domain-specific knowledge. Predictive analytics models take advantage of developments in computational infrastructure and low-cost data capturing and storage capabilities to process large-scale manufacturing datasets and connect such diverse data as engineering records, assembly operations, material properties, in-process measurements, and sensors. The value proposition of predictive analytics models has been realized in various functions within the manufacturing organization and currently includes applications in the areas of quality assurance, production optimization, supply chain optimization, equipment maintenance, and assessment of product sustainability and end-of-life performance. Companies have realized significant benefits—such as cost savings, increased efficiency, and higher quality—associated with problem prevention instead of mere problem detection.

The vehicle manufacturing industry faces the challenge of transitioning to a carbon-neutral operating model as well as producing cars with the specific materials and structural behaviors that enable energy efficiency and recyclability of materials at the end of the product life. These long-term strategic goals for the year 2050 are built by the recently introduced Planet 2050 vision. In the context of large-scale industrial startups, the integration of predictive analytics is complex. This originates from two factors. The first is that several of the predictive analytics applications require learning models to be trained on data batches over long periods. The other factor limiting the integration of predictive analytics in large-scale industrial startups is the scarcity of data in the absence of industrial operations. While these data challenges are specific to large-scale vehicle startups, existing and emerging predictive analytics methodologies offer a variety of solutions to these problems. The value proposition of the predictive analytics models is to support the transition of car manufacturing from design and development to high-volume production units embedding properties that are sustainable over the lifespan of the vehicles.

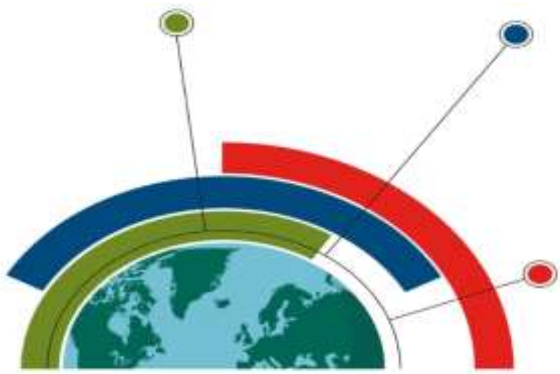

Fig 5 : Predictive Analytics in Planet 2050

5.1. Case Studies and Best Practices

In the initial sections of this chapter, we provided an overview of the need for the vehicle industry to evolve into the future and the establishment of projects. In this section, we will present a set of case studies and best practices of the industry leaders who have taken steps toward developing the future of mobility. These examples demonstrate cooperation and commitment within a coalition of industry peers and provide a foundation for future improvements. At the end of the chapter, we conclude with some recommendations to guide the industry's participants toward their targets.

In this section and the next chapter, we celebrate and demonstrate the significance of these projects by sharing them with you. These case studies encompass a broad set of ideas on various tangible sustainable innovations leading to the execution of the projects. Please bear in mind that the activities presented in these case studies are likely the results of the combined efforts of several participating partners. To start with, the first subsection focuses on the shared knowledge within the industry, demonstrated by the construction of the consortium of industry leaders. We then showcase the successful historic effort by another much broader industry initiative. It is followed by the examination of the successful initiatives of the individual OEMs regarding the future manufacturing and use of electrified vehicles.

6. Conclusion and Future Directions

In conclusion, this paper represents an attempt to understand the latest advancements and global trends within the field of large-scale vehicle manufacturing to highlight the critical factors and determine key initiatives, both in terms of production using the concept of transparency-enterprise and in terms of the Planet 2050 requirements. Step Route 10 has been identified to present the current variable obsolescence of the traditional economic models for vehicles. It is considered that the development of a 'Model R for Replacement' can be of crucial importance to vehicle manufacturers (and also to those of the components for the sector).

Finally, since the collection and analysis of massive data has disaster avoidance potential, the embracing of the human-made challenge and the anticipatory analysis process to quantify disaster avoidance potential as well as to quantify the access to permanent space model role of the vehicle manufacturing sector eye view forecasting tools potential is also considered of utmost importance. The ability to dominate the process of large-scale vehicle manufacturing is a precursor to both the ability to dominate the planet Earth and the ability to leave the Earth and arrive at the planet Mars. The paper presents different research questions that will be addressed shortly. The study was focused on the present sector's production process using the concept of transparency-enterprise as Route 9 aimed at defining the transparency domains. The additional development and use of AI might also permit the achievement of transparency domains for each consumer's requirements, pointing to Route 8. More generally, the requirements of Planet 2050 have been analyzed, highlighting the critical factors and determining some key initiatives in a step-exploratory way. It is considered that the development of a 'Model R for Replacement' can be of crucial importance to vehicle manufacturers (and also to those of the components for the sector). It is believed that the paper provides an interesting starting point to address the conclusion and future directions that arise from it.

Equation 3 : Production Efficiency

To calculate the efficiency of the production process, use:

$$E = \frac{O}{P} \times 100\%$$

Where: E = Efficiency (%)

O = Output produced

P = Potential output (maximum capacity)

6.1. Key Findings and Implications

Key Findings. Efforts are made to integrate the different perspectives of the five papers in this set to provide cross-cutting implications about state-of-the-art large-scale vehicle manufacturing, lessons learned, future directions, and concrete findings. These key findings include the need for a reset on the factory of the future path due to the uncertainties surrounding the introduction of new technologies. Future modules should encompass knowledge sharing and collaboration within academia and between academia and industry. In addition, an open dialogue platform should also be formed to engage society in the conversation about the future development of vehicle manufacturing. Other key takeaways include analyses of technology advancements, disruptive management systems, streamlining of large complex manufacturing structures, big data creating opportunities, and public policy considerations.

Implications. The lessons learned from the success stories included in these five papers show that the advancement of new and disruptive technologies has created new ideas to improve vehicle manufacturing systems. The excitement for the newly introduced management and control structures is very high. Companies have started pilots or full implementations with a relevant impact on operational efficiency and cost reduction. However, in many cases, technologies are not fully reliable and present several disadvantages in adaptation for the automotive industry and the regional context. The high investments required, with the long payback period, and the conservative approach of most industries may delay the inclusion of these technologies in large-scale automotive manufacturing plants. In the companies' mindsets, the exploitation of existing assets with incremental improvements prevails as the most profitable alternative option. However, despite the current situation of the developed technologies, several conclusions can be extracted and indications can be forwarded for an effective redefinition and development of vehicle manufacturing plants.

6.2. Recommendations for Industry and Research

After a critical reflection on the outlined objectives of the 50 on 2050 initiatives, several key aspects could be deemed relevant for policymakers, industrial, or research stakeholders engaged in innovative manufacturing and supply chain or logistics initiatives. 1. Continuing in science matters training and discussions to ensure that any issues resolved during the programs are sustained in the future and not just an illusion that will fade away. Demonstrate effective strategic behaviors that favor the development of innovative solutions. The mining industry has benefited from technology innovation in remote instrumentation and has achieved remarkable upgrades quicker compared to conventional manufacturing. Highlight region-wide contributions in leading thematic areas. 2. For Research Extend knowledge of underpinning micro and nanomaterials and improve the in-service properties and environmental stakes of the components, hence enhancing human safety and ecosystem equilibrium. Connect the projects and the skills base of the stakeholders, in addition to developing novel mitigation and prevention strategies. Demonstrate a long-term commitment to innovative technology.

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