Smart Manufacturing of Electric Vehicles

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Abstract. The future of the manufacturing sector is evolving with the Industry 4.0, and its repercussions are felt in the factory, the business, product launch and also impacts customer aspects in the overall cycle. These technological innovations create opportunities for new disruptive entries to the market, for instance in automotive manufacturing. It is well known that the automotive industry is under the control of large OEMs since the very beginning. It is very difficult to compete as a newcomer because the production process of the Internal Combustion Engine (ICE) and the chassis require high technology, investment, and a well-defined supply chain that create a monopolistic environment for the sector. Therefore, we propose a microfactory concept as a novel manufacturing method that allows a quicker entry for new players in the automotive industry especially for electric vehicles (EVs).

The microfactory described in this paper, presents an alternative solution to overcome the existing monopolies with the electric motor, a tubular chassis allows for lean manufacturing, and a novel supply chain model. Digital transformation shows itself in production systems by Industry 4.0 applications and more recently in the blockchain-based supply chain applications are being investigated. Further, a detailed cost analysis to compare conventional car manufacturing and microfactory concept EV manufacturing are presented. In addition, the blockchain technology is proposed to improve the supply chain of EV manufacturing. This study indicates that the microfactory provides flexible and customized production of urban electric vehicles minimizing both ecological footprint and total investment.

Keywords: Advanced manufacturing technology · Electric vehicles · Flexible manufacturing · Sustainable production · Sustainable supply chain · Automotive industry

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1 Introduction

Almost a century later, electric vehicles are being discussed as a superior alternative in many ways to conventional ones, thanks to recent technological developments. The increasing trends in smart city concepts have also affected electromobility needs towards autonomous/electric vehicles (EV) with high security capabilities. Because, the mobility needs such as safety, lower emissions (CO_2, noxious gases, noise), congestion, energy security, employment and the resources can be met by safer, more efficient and lower footprint electric vehicles. With this motivation, the automotive industry is in the transformation process from Internal Combustion Engine (ICE) to electric motors to reduce global CO_2 emissions. Thus, the electrification, connected vehicles, changing ownership models and autonomous driving are important trends transforming the industry. The sales rate also verify that there is an increasing trend in EV sales year by year, for instance global stock of electric passenger cars reached 5.1 million units in 2018 [1] and global plug-in vehicle sales reached 2.2 million units for 2019 which was 2.1 million for 2018 and 64% higher than in 2017 [2]. China is still the largest growth contributor, with 1.2 million EV sales, which are 56% of all EV sales in 2018. For European market, plug-in vehicle sales -include all Battery Electric Vehicles (BEV) and Plug-in Hybrids (PHEV), passenger cars and light commercial vehicles reached 408 000 units in 2018, which is 33% higher than in 2017. Norway is the share leader, where 40% of new car sales were Plug-ins in 2018, Iceland and Sweden following closely. EV sales in USA increased by 79%, and Tesla Model-3 is the main contributor [1, 2].

1.1 Mobility Needs and Trends

Mobility as a service (MaaS) providers need safe, personalized and small EVs (four/three/two wheels) with affordable prices. To decrease the total cost of ownership, new manufacturing models should be developed for low investment, flexible and multipurpose platforms which have high convergence with renewable energies. EVs are claimed as the best alternative for environment, however, even though EVs have zero tailpipe emissions they are not GHG emissions-free when evaluated on a well-to-wheel basis. Nonetheless, increasing debate on electrification leads to some interesting future scenarios for 2030. Many reports indicate that the electromobility leads to a radical reduction of green gas emissions and use of oil [1, 3, 4, 5, 6]. For instance, a typical mid-size EV can generate up to 67% lower GHG emissions than a gasoline ICE car on a well-to-wheel basis [7, 8] which means they pollute much less than their combustion engine counterparts. As technology becomes widespread, it is likely to become more efficient and sustainable. Economies of scale will benefit EV manufacturing by offering better infrastructure, more efficient production techniques, recycling options and reducing the need for the mining of new materials.

However, to be competitive in the automotive sector, which consists of different sub-segments, using existing manufacturing infrastructure and products, it is difficult to penetrate and get an international market share for new comers. Because the current production systems heavily depend on conventional manufacturing where high capital cost and high technological knowledge required to operate, is mostly under the control of large OEMs. Indeed, the demand for higher quality, lower cost, and more customizable mobility systems leads transportation-related industries to invest more in advanced, smart, and sustainable technologies in the production of higher quality, affordable, energy-saving, competitive, and customizable vehicles. The microfactory can break this monopoly between large OEMs and Tier1 suppliers for new comers or emerging countries who want to manufacture their national car brands.

For the purpose, this paper represents the microfactory model as an alternative solution to automotive industry to produce EVs in a smart way to meet the urban mobility needs.

2 Microfactory Concept

The main drawback of conventional manufacturing is the complexity of conventional chassis of vehicle (Fig. 1). The huge investment is needed to produce body in white (BIW) because of the complexity of operations for moulds to shape metal sheets in a 3D geometry, followed by complexity of tooling for welding operations. Moreover, the conventional manufacturing needs large production volumes to reach ROI, which also leads to giga-scale production plants. The another challenge of this existing system is the lack of flexibility in production lines, for instance there is a great difference in operations between the chassis with one and two-doors on the same side.

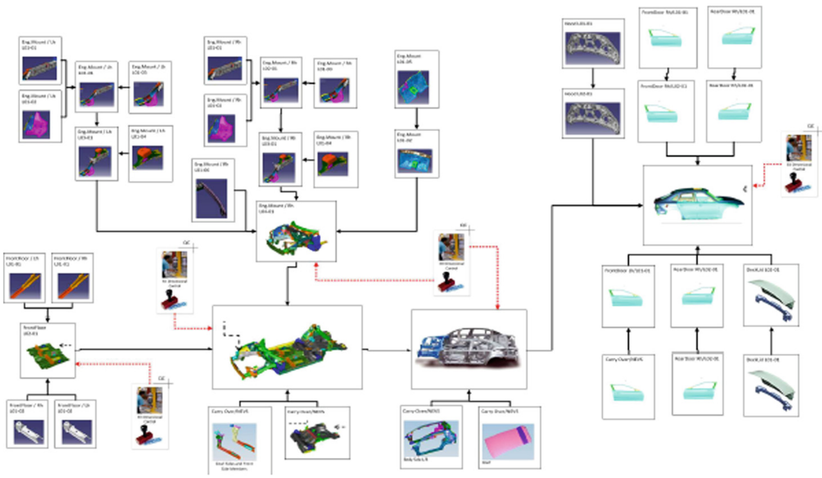

Fig. 1. The conventional assembly line

A remarkable novelty has been introduced in this study which involves a tubular-based chassis design to facilitate the coupling of body panels. The developed tubular chassis using a blend of super high strength steel (SHSS) with defined characteristics on the strength, the thickness, and sizes is manufactured with no moulds and simplified templates. Moulds are the major cost items in conventional manufacturing lines. The result is that very low investment is needed to meet the most severe EuroNCAP crash tests (full frontal, off-axis and side crash tests). Therefore, the microfactory described in this paper, differentiates itself as a concept, which can be defined as low investment manufacturing of safe, low footprint, secure and efficient urban electric vehicles using digital technologies. Within the microfactory, the production can cover all needs for urban mobility from e-bike, 3 wheel to 4 wheel vehicles with minimal additional efforts. Each microfactory is conceived to produce 50 vehicles/day over 2 shifts, all the production processes from laser cut, assembling of the chassis, assembling of the powertrain and the battery pack, painting, the integration of interior and external parts (panels, lights, sensors, seats, etc.) and testing are performed inside this factory. For the purpose, a 10,000 msq plant is enough (Fig. 2). When the demand exceeds what is possible in the third shift, another microfactory has to be established thus introducing parallel manufacturing concepts.

Fig. 2. The energy independent microfactory

The proposed design is also characterized by allowing the manufacturing of considerably different architectures with minimal changes in the production line. Figure 3 shows different architectures resulting from a flexible manufacturing assembly line: small changes to the chassis used to manufacture a pickup car, a food delivery and restaurant car allow the switch to passenger cars and taxi models. In summary, new investment is not required to produce six different platform architectures that can be further personalized to about 120 different aesthetic body panels within the microfactory.

Microfactories are highly integrated with Industry 4.0 technologies. The automation infrastructure of Microfactory is provided by automotive assembly line manufacturers such as Comau. The microfactory co-developed with Comau is capable of the batery assembly, e-motor assembly and body assembly, presented in Fig. 4. Microfactory provides a simplified manufacturing layout which allows minimal changes in the chassis to manufacture in a flexible way a variety of vehicles. The robust SHSS steel-based chassis eliminates moulds in production line with appropriately designed in 3D printed parts.

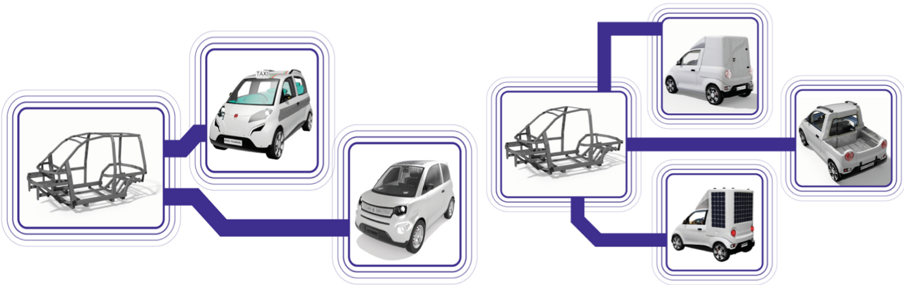

Fig. 3. Flexible manufacturing

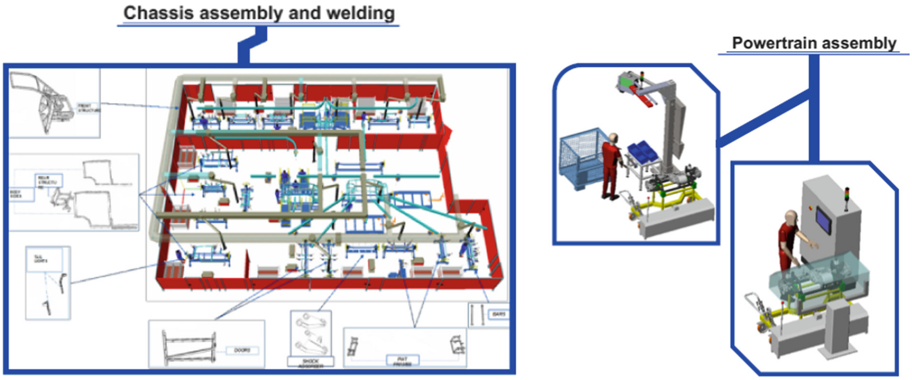

Fig. 4. The assembly line of microfactory

2.1 Cleaner Energy Management

Electric motors have zero tailpipe emissions when it compared to ICE vehicles. The source of energy is crucial to make EVs superior to conventional cars. The micro-factory is designed as energy independent which the solar panels produce the necessary energy to run the factory (Fig. 2).

The technological developments in batteries triggered the launch of EVs in the industry today. The research in these two fields are supporting each other. These innovations lead to decrease in battery cell prices too, for instance, the price of battery cell for global automakers was around \$700 in 2013, it is assumed that it will fall by 40–46% until 2025 and, it will almost catch to the Tesla's battery advantage for the industry [9]. Lithium-ion battery pack prices have fallen by 21% every year and remained at \$176/kWh in 2018.

In line with the EV growth, different players along the battery supply chain are increasing the capacities of the module and the package production. For instance, Tesla has the 239 GWh Li-on capacity for the module and pack, Volkswagen has 206 GWh for a pack, and Daimler has 72 GWh for module and pack [10]. Within the micro-factory approach, the battery tray should achieve high-level thermal control, allocated a maximum possible battery capacity, be ergonomic for driver and passengers and easy to install while keeping the investment as low as possible.

2.2 Sustainable Supply Chain Model for Microfactory Network

The local supply-chain network is proposed for a microfactory. Even if the product is conceived and assembled inside the factory, there is still a need of a well-defined supply chain for critical components such as the motor/inverter, tubular SHSS, electronic board lights, seats, battery cells, etc. However, low volume manufacturers cannot easily reach the large Tier1 automotive suppliers, in fact in most cases from a supplier point of view; it is not worth to supply a single microfactory. When microfactories located in different regions share the use of components/systems the interest of large Tier1 changes. The collaboration among microfactories transforms their weakness into strength as if they behave like a single large company. The same concept applies on their influence on national-international standardization and regulations. Since the microfactories can be designed for Industry 4.0 operations, by replicating microfactories in different regions automation capability enablers such as COMAU, the CLN group or others would potentially provide strong market entry for microfactory concept in car production.

In summary, the microfactory as it is originally conceived here is an approach, which finds its most attractive application when replicated in different locations. Cooperative R&D&I among different microfactories decreases the engineering cost while increasing the social sustainability from many aspects including promotion of youth employment.

Each microfactory must be able to produce its own brand with customization according to demand of its local market. The idea is that the collaboration with other microfactories will make local brand stronger. To sum up, this kind of supply-chain model for the microfactory concept allows cooperation of companies while they are economically independent entities.

For final note for microfactory concept, a blockchain integrated supply chain model can be designed for microfactory networks, since blockchain provides transactions among parties using collaboration and cryptography while eliminating intermediaries [11]. As a result, proposed microfactory model can have fast and secure supply chain model enabled with blockchain technology.

3 Conclusions

The transformation need of the automotive industry towards electrification creates a new market that has the opportunity to break the existing monopoly. In relation to this, connected vehicles, changing ownership models, and self-driving cars become new technologies to be investigated.

In this study, we presented the trends and opportunities towards electromobility and proposed a microfactory approach which provide flexible and customized production of urban electric vehicles minimizing both ecological footprint and the total investment.

For future studies, the blockchain integrated supply chain model can be studied in detail for microfactory network and more quantitative research can be obtained with the application of this proposed system.

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