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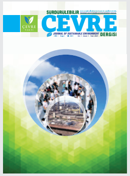

Microfactory Model for Manufacturing New Generation Electric Vehicles

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Abstract

The electromobility presents a potential opportunity for nations to develop and produce their domestic cars especially for emerging markets. This paper proposes a new concept, called microfactory, for manufacturing Electric Vehicles (EV). It is a big challenge for newcomers to enter the automotive market as this industry remains heavily under the control of large OEMs (Original Equipment Manufacturer). There are three main de facto monopolies in the automotive industry; the first two of them are the required technology and knowledge to manufacture the Internal Combustion Engine (ICE) and the chassis, and the third one is the difficulty of reaching government funding. The microfactory represents an alternative solution to overcome the existing monopolies with the electric motor, a tubular chassis, and a novel business model respectively. A detailed analysis of the difference between conventional techniques and new production paradigm is presented in this work. The principles of the microfactory from the layout to the supply chain management including the sharing economy are presented. This study indicates that the microfactory is a sustainable production model for manufacturing of safe, secure, customized and efficient urban electric vehicles using smart manufacturing tools in small-scale production with low investment. The aim of this paper is to propose a new disruptive manufacturing method that allows a quicker entry for new players to the automotive industry especially for EVs.

Keywords: Automotive industry, electric vehicles, flexible manufacturing, microfactory, smart manufacturing, sustainable production.

Mikrofabrika Yöntemiyle Yeni Nesil Elektrikli Araç Üretimi

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Özet

Bu çalışmanın öncelikli amacı, sayıları az büyük otomotiv üreticilerinin tekelinde olan sektöre yeni bir üreticinin girmesine olanak sağlayan yeni bir üretim konsepti sunmaktır. Mikrofabrika konsepti ile içten yanmalı konvensiyonel araç üreticilerinin domine ettiği sektörde yeni nesil elektrikli konsept araçların üretimi için kobilere ve yerli otomobilini üretmek isteyen ülkelere rekabet edilebilir bir alternatif sağlanmaktadır. Geleneksel otomotiv üretimi, içten yanmalı motor ve şasiyi üretmek için gerekli teknoloji ve bilgi birikimi, ve devlet teşviklerine ulaşmanın zorluğu nedeniyle birkaç büyük OEM (Orijinal Ekipman Üreticisi)'in kontrolü altındadır. Mikrafobrika konsepti bu zorluklara karşı sırasıyla elektrik motor, tubuler şasi yapısı ve paylaşım ekonomisine dayanan iş modeli sunarak yeni üreticilere pazarda bir fırsat yaratmaktadır. Makalede mikrofabrika teriminin literatürdeki karşılıkları analiz edilmiş, ve bu çalışma kapsamında sunulan konseptle literaturden farklı olarak elektrikli araç üretimi için özgün bir mikrofabrika yöntemi tarif edilmiştir. Konvansiyonel teknikler ile yeni üretim

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paradigması arasındaki farkın ayrıntılı bir analizi yapılmıştır. Mikrofabrika konsepti için, yerleşim planı, operasyon aşamaları, paylaşım ekonomisine dayanan tedarik zinciri yapısı ve iş modeli detaylarıyla sunulmuştur. Önerilen yöntem sürdürülebilirlik açısından da incelenmiştir. Bu çalışma, mikrofabrikanın, akıllı imalat araçlarını kullanarak, düşük ölçekli yatırımla küçük ölçekli üretimde güvenli, kişiselleşmeye uygun ve verimli şehir tipi elektrikli araçların üretimi için sürdürülebilir bir üretim modeli sunduğunu göstermektedir.

Anahtar kelimeler: Akıllı üretim, elektrikli araçlar, esnek üretim sistemleri, mikrofabrika yöntemi, otomotiv endüstrisi, sürdürülebilir üretim,

1. Introduction

Recent advances in batteries, electric motors and power electronics technologies and environmental considerations bring the electric vehicles (EV) on the forefront of transportation. Technology advances such as developments in battery chemistry and expansion of production capacity in manufacturing plants provide significant cost reduction. It has been recently highlighted in Global EV Outlook that new solutions in EV manufacturing take advantage of the modular vehicle manufacturing platforms with simple and innovative design architecture including battery systems, coupled with big data infrastructure (2019). The EVs are superior to conventional fossil fuel vehicles in terms of sustainability, efficiency, convenience, and fuel economy and its worldwide adaptation is growing. Research is continuing to overcome some limitations such as long charging times, limited availability of charging infrastructure and the cost of batteries. Although electric vehicles appear to be the best for the environment with almost zero emissions in traffic, environmental and investment issues related to their manufacturing processes are still a concern (Hackwill, 2016). Therefore, new manufacturing methods to produce environmentally friendly, reliable and affordable EVs are needed. There is also electromobility trend which requires high cybersecurity capabilities for autonomous vehicles. The transformation process is moving remarkably fast from Internal Combustion Engine (ICE) to EVs with electric motors to reduce world's CO2 emissions. Global stock of electric passenger cars reached 5.1 million units in 2018 (Global EV Outlook, 2019) and global plug-in vehicle sales reached 2.2 million units for 2019. This was 2.1 million for 2018 which is 64 % higher than in 2017, and %57 higher than 2016, these sales rate shows there is an increasing trend in EV sales year by year (Irle, 2019). Moreover, China led the growth with 1.2 million EV sales, 56% of all EV sales in 2018. Plug-in vehicle sales - reached 408 000 units in 2018 in Europe. EV sales increased by 79 % led by Tesla Model-3 in the US. (Irle, 2019; Global EV Outlook, 2019).

Although many improvements in EV technology in terms of performance, the efficiency, the styling, availability and the demand are increasing daily, EV remains more expensive to manufacture. Thus, manufacturers are looking for new production methods. A recent study by Kim et al claimed that, the future factories should be smarter in order to quickly respond to customer requirements, maintenance services for unseen failures, and allow quick retrofits. They propose a modular factory testbed which has rapid workstation, self-layout recognition, robot reprogramming, interlayer information sharing and a configurable software for shop floor examination (2019). Today, the demand is more on customization, and the manufacturers need rapid manufacturing technologies, which are the main considerations of distributed manufacturing and its sub-focus areas.

In this paper, a microfactory is introduced to address smart and innovative manufacturing model to produce an EV as an alternative manufacturing method that enables sustainable production. First, a variety of related definitions of microfactory as discussed in the literature is reviewed and a new definition for microfactory concept for EVs is proposed. Then, the conventional approach to car manufacturing and its drawbacks are described. Subsequently, Microfactory concept is proposed to overcome the monopolies of existing car manufacturing industry as a disruptive manufacturing model. The microfactory model is compared with the conventional manufacturing in detail in terms of technological knowledge, the business opportunity, and sustainability dimensions. Thereafter, the microfactory plant is presented from the layout to manufacturing operations to produce an EV. In the final section, the blockchain technology is discussed to develop a microfactory supply chain management for this industry.

2. Methodology

The difference between current conventional manufacturing and microfactory concept for electric vehicles is reviewed in this section. A production layout designed for microfactory is presented. The proposed microfactory concept will allow lean manufacturing flow mainly because it is a process that eliminates the use of dies and moulds, which makes up the main cost items for manufacturing investments.

2.1 Review of factory concepts

The vagueness in defining distributed manufacturing is discussed previously (Fox & Alptekin, 2018). Similarly, the variety of definition in the term 'microfactory' exists in literature. According to taxonomy of distributed manufacturing, modular manufacturing system, flexible manufacturing, smart factories, the factory of the future, mini-factories, and eco-factories, digital manufacturing, Industry 4.0 era, are the most commonly used keywords in literature related to distributed manufacturing. Since the high integration of automation in production operations, these factories are classified as 'unlit/dark manufacturing' under the industrial distributed manufacturing (Fox & Alptekin, 2018).

The Factories of Future (FoF) is desired to be able to meet the increasing demand for greener, more personalized, and higher quality products through the Industry 4.0 revolution. Thus, FoF creates a flexible, digitalized, and demand-driven industry while decreasing energy consumption and waste generation. (EFFRA, 2021) Over the past decade, with the implementation of recent emerging technologies such as Cyber Physical Systems (CPS), and Internet of Things (IoT), Industry 4.0 shapes the future manufacturing in terms of factory, business, products and customers (Qin et al, 2016). Smart factories, which enable a quick response to customer demands with high flexibility even in small lot sizes while satisfying human-machine integration in manufacturing operations, are the result of this revolution. Germany, the USA, Japan, and Korea are the leading countries that have established national research programs on smart manufacturing (Thoben et al, 2017).

A 'Mini-Factory' is defined by Zanetti et al as a small-scale production unit able to make customized products with low cost and short delivery time (2015). These factories are designed to be scalable and modular allowing quick chan-ges according to customized based goods (Matt et al., 2015). This feature provides adaptable production systems, but the factory is designed as fixed and small according to Giga factories (Rauch et al., 2016). The proximity to custo- mer is another feature of mini-factory to quickly respond to his/her specifications, thus it has the capability of producing customized products and provide customer service including repair and maintenance (Reichwald et al., 2005). Furthermore, a specific classification for microfactory systems was offered as a manufacturing method by desktop factories through the use of small robots to produce small products (Kawahara, et al., 1997). In general, the mini, micro, and desktop factories are sustainable production systems suitable for micro assembly, because it saves energy and factory floor space. In particular, TUT microfactory module which has the dimension of 300x200x220 mm, defined by Tampere University of Technology (TUT) as a modular construction kit-type concept with an easy and rapid re-configurability for different manufacturing process of small products (Järvenpää et al., 2013).

Microfactory retailing is proposed as a system-level change in the automotive industry to enable the economic viability of small-scale localized manufacturing sites in for vehicle production. It allows the adoption of a full-scale product service system (PSS) at local levels with the advantages of the merging of the commerce and manufacturing function, and the proximity of manufacturing and servicing sites to users (Williams, 2006). The maker movement platforms also use the Microfactory concept as the place where the product is engineered for innovation and collaboration. Through the access of the latest technology, it gives the opportunity to creative minds to reach all the tools to design, prototype, or put the final touches on their inventions. Using advanced manufacturing techniques with rapid prototyping tools helps move products quickly from the concept to the creation and to the showroom floor (FirstBuild, 2019).

Much of the current literature on Microfactory pays particular attention to describe the small desktop manufacturing systems. The term Micro Factory Retailing (MFR) has been used for last two decades for low volume manufacturers and it is proposed as an alternative, more sustainable business model for automotive manufacturers (Nieuwenhuis,2018). Throughout this paper, the term microfactory is defined here for high volume manufacturing of electric vehicles. This approach is previously described as an application of smart manufacturing in automotive manufacturing, eliminates the major cost items in production line such as the press and dies in car manufacturing, reducing plant investment dramatically (Alptekin et al, 2020). The key features of a microfactory are lean, flexible production, feasibility of Industry 4.0 and economically scalable manufacturing plants. The recent study by Stavropoulos et al presented a decision support system for this proposed microfactory case. They estimated the cost of integration laser welding in automotive manufacturing according to microfactory' and OEM's perspectives and concluded that the major impact of digitization and sustainability leads microfactory to become profitable even if there exists a large amount of uncertainty (Stavropoulos et al, 2021). The aim of this study is to expand this new concept of manufacturing through microfactories that will allow flexible and customized production of electric vehicles, minimizing both environmental footprint and the needed total investment.

2.2 The conventional approach to car manufacturing

The current car factory assembly line has been designed by European assembly line builder is described with its technical characteristics in detail by Michalos et al (2015a). Since the first mass-produced car Ford Model-T, the manufacturing has evolved tremendously in terms of both materials and processes with more and more advanced automation and robotization. A huge investment is needed to produce the body in white (BIW) which is made today by stamping of metal sheets (either advanced steels or aluminum), followed by robotized welding assembly. Michalos et al. (2010) point out that existing assembly plants are not flexible enough to meet the increasing demand for more customized vehicles. The current systems are lacking the capability to provide the product variability at a low cost and shortest time possible. The main stages of automotive manufacturing are stamping, body shop or body in white (BIW), painting, pre-assembly and final assembly (Nieuwenhuis,2018) and high-level automation is required in BIW while more human-machine integration (HMI) is needed in final assembly. Fixtures are used in conventional car manufacturing to meet high production volumes at low cost, however, they are not sufficient when the product variety increases. But still, fixtureless assembly is not viable due to cost reasons (Michalos et al.,2010). To reach the high reconfigurability and autonomous line, mobile robotic units, modular and flexible end effectors, high automation, are desired elements for future assembly plants (Michalos at al,2015b).

The brief description of the conventional car manufacturing process is as follows; large moulds are used to stamp metal sheets by a servo transfer press that reach 1000-5000 ton force. These servo transfer presses are highly integrated with advanced automation, and human activity consists of setting up the moulds and the parameters of the presses. For instance, Nissan presented 5200-ton servo transfer press which requires extra-large press area to use in Sunderland plant (Nissannews, 2017). A vision of the robotized welding islands to assemble the stamped metal sheets and the final lower part of the chassis are other examples to illustrate the complexity of operations in current car manufacturing plants. Thus, the conventional system requires very high investments for tooling, the press, special paint and surface treatment technology (Nieuwenhuis and Katsifou, 2015), which is affordable only to established OEMs, addressing the large production volumes necessary to assure the return of the investment (ROI). Because of this complexity and cost, this method of manufacturing lacks reconfigurability and flexibility, which limits the customization.

Similarly, to the chassis, the manufacturing of innovative ICE requires huge investments and knowledge representing another big obstacle to anyone addressing the development of plug-in hybrids and/or ICE based range extended electrified vehicles.

Today, the established car makers, because of the above mentioned large investment, the knowledge required and complexity of the business, control the market and the relations with the governments. In fact, the automotive industry is a major source of employment and technology development of a nation. It is very hard to compete with the established OEMs in their fields. A new manufacturer to be successful needs to introduce breakthrough technologies. That is, it has to overcome the existing monopoly on motorization, manufacturing and marketing/selling. Tesla, which recently entered into the pickup market with an extraordinary designed product, named Cybertruck can be given as an example of newcomer's strategy. The design of Cybertruck has an exoskeleton (body and frame are one piece) instead of the traditional body-on-frame (the body is assembled on a frame). This new frame structure provides significant advantage for space especially for the battery packs. The simple plate-like design provides cost savings (Nanduri, 2019). The main advantages of this frame design are to minimize manufacturing and assembly operations, and eliminate painting, where these cost reductions become important especially when the producer is a new player in the existing market. This can make the process more sustainable in terms of the cost and the environment. Cybertruck is just one example, if there is a new comer in the already mature sector, it must differentiate itself by innovation in design, technology as well as cost reductions. With this perspective, the microfactory suggests a breakthrough-manufacturing model to produce new generation EVs.

2.3 Microfactory concept for car manufacturing

The conventional automotive industry has three main de facto monopoly; Internal Combustion Engine (ICE) includes full of complexity, chassis require high initial investment cost, and government funding is difficult to reach.

To overcome these monopolies, there is a need for simpler and cheaper manufacturing concepts implementing environmentally friendly processes while addressing vehicle's performance on efficiency, safety, and security at the highest levels. Tesla provides an interesting example that has challenged the conventional automotive industry on powertrain development and marketing approaches. However, the manufacture of Tesla chassis (BIW) remains largely conventional. Huge investments are still necessary to produce the chassis and consequently, the return on investment (ROI) can be achieved only when large volumes are made. In fact, none of the electric vehicles currently in the market has led the OEMS to reach the necessary ROI. Table2.1 summarizes the main disadvantages of conventional manufacturing

Table 2.1 The monopolies of conventional car manufacturing and microfactory option

Conventional car industry	Disadvantages	Solutions by Microfactory
ICE	1billion instruction/sec +15 actuators +15 sensors	Fully Electric powertrains set new boundaries
BIW	Using moulds to produce BIW costs tenths of millions Production line costs >100M€	New manufacturing technics; Tubular chassis architecture and SHSS eliminates moulds
Public Funding	Governments will continue to invest on large OEMs to keep jobs	If the new comers are supported by government incentives, it leads to generate national technologies.

and solutions offered by the microfactory concept. Microfactory model described in this study simplifies these items in automotive manufacturing.

The electric powertrain challenges the first monopoly. Here, the monopoly refers to the difficulty of entry for newcomers. Focusing the attention on the powertrain, the question for a new manufacturer is to secure the supply chain. The important point here is to define the right designs and selecting the right suppliers to be independent from critical components/systems. The conventional automotive manufacturing relies on alternative suppliers even for the simplest components. To emphasize the concept, within the automotive manufacturing, it is usual to state that a supply chain is properly secured when each screw could be purchased from three different suppliers. For instance, consider the power electronics: there are only two large semiconductor companies in Europe (such as Infineon and Cypress) that could provide high power semiconductor chips and few manufacturers of power electronic modules. When a new company designs its Powertrain, it should consider the related constraints. Motors/Inverters operating at 240V and 360V or above are usually produced by difficult to approach large suppliers, strictly connected with existing OEMs. Motors and inverters operating at 100V (MOSFET technology) are usually produced by easy to approach manufacturers. At this voltage, the efficiency of the powertrain can be made extremely high satisfying the needs of all emerging markets in urban mobility. When addressing the freedom of operation, the choice of voltage is then straightforward.

Aiming at decreasing the fuel consumption the automotive industry has been able to replace the steel with the aluminum, sometimes reducing the total weight up to 20-30% (Miller & Ramsey, 2014) (Djukanovic, 2016.) With the advent of Super High Strength Steel (SHSS), it has been demonstrated that for the same structural characteristics, a chassis based on SHSS can be made lighter than alternative solutions based on aluminum. This is also affecting manufacturing processes including cost and recyclability.

For mid and low volume productions tubular-based chassis had been introduced since the very beginning of the automotive industry. Based on crashworthiness analysis, the tubular chassis showed that it has high performance and excellent rigidity/weight ratio value, therefore reduce fatalities in case of road accident (Boria et al., 2015). Hitherto, tubular-based chassis have found limited applications in large-scale productions for instance for racing cars. In fact, starting from a tubular chassis the integration of body panels requires complex steps difficult to justify both economically as well as from a robustness point of view. Meeting both cost and robustness is a difficult problem when trying to match the geometry of the chassis with the closing panels in fact to find cost-effective engineering solutions remains a big issue of the automotive industry. Many organizations that started working with tubular chassis when moving to large-scale productions have returned to the usual approach based on the metal sheet stamping.

The major novelty of this study is the simpler coupled of the body panels due to innovative tubular-based chassis. The tubular chassis structure with a SHSS enables manufacturing without moulds, enables high strength and variety of sizes. This enables low investments in crash test cycles (full frontal, off-axis and side) for the industry, to meet the most severe EuroNCAP requirements.

The production line required is greatly simplified with this model where the proposed design could have different architectures. Figure 2.1 indicates a flexible manufacturing assembly line: small changes to the chassis used to manufacture a pickup car, food delivery and restaurant car allow the switch to passenger cars and taxi models. New investment is not necessary in the microfactory to manufacture six different platform architectures up to 120 different aesthetic body panels.

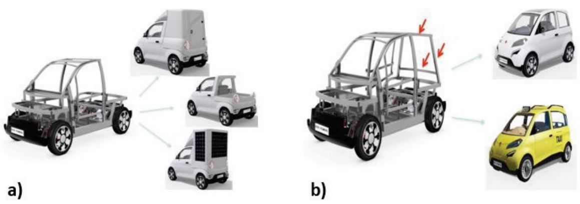

Figure 2.1 The same chassis for pickup, food delivery and restaurant cars (a); same chassis for passenger and taxi cars (b)

In literature, although the main principles appear to be similar, the term of microfactory has to be related to a specific product and field. The microfactory concept is a remarkably different than conventional methods since it enables low investment for a lean, safe, low footprint, secure and electric vehicles with highly digitized systems. The production is highly flexible where an e-bike, 3-wheel to 4-wheel vehicles can be manufactured with small modifications. A 10,000 msq plant is assumed in this study, demand met using 3-shifts. Higher demands will require introducing parallel manufacturing concepts. Figure2.2 summarizes graphically conventional and microfactory car manufacturing concepts.

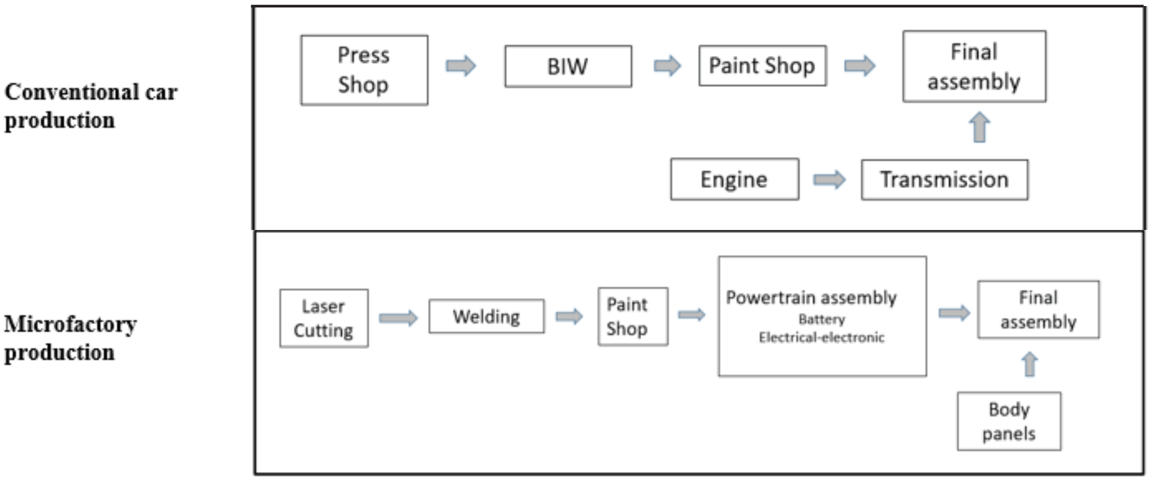

Figure 2.2 Conventional vs microfactory car production concepts

Since major investment and knowledge are required for current conventional car manufacturing, the alternative manufacturing strategy microfactory concept can radically decrease the cost with dieless manufacturing and a tubular chassis structure.

3. Opportunities in EV/Car Industry

The automotive industry produces all kinds of motor vehicles needed by the tourism infrastructure, transport, and agriculture. Therefore, any changes in this industry directly affect the economy. This sector is fundamental to the working of the global economy and is a powerful contributor to the prosperity of the societies. The automotive production chain has a strategic role in most industrialized countries contributing to the national production, industrial development and employment (Cinicioglu et al., 2012)

Since there is a de facto monopoly of the conventional ICE motorization, it is difficult to enter the car making industry. Electromobility represents an opportunity for emerging markets to produce their own cars with national technologies. Large potential markets for Microfactories exist in Turkey, Russia, Poland and all other regions in the world having strong manufacturing capability in automotive and strong motivations to establish their own national brands.

Other potential markets for microfactories are among mobility as a service provider “MaaS” (ride-hailing and ride-sharing companies, (Zenner, 2015)) which need mostly small vehicles. These companies usually have high capitalization and large cash but do not have the capability to produce their own vehicles.

Consequently, they use what has been offered to them by the large OEMs. A microfactory offers quickly to implement solutions to their ever-increasing needs.

Microfactories can be designed adopting most advanced Industry 4.0 technologies without existing constraints. In this context, Industry 4.0 methodologies and technologies are proposed. Utilizing automation capability enablers, automotive assembly line manufacturers would potentially provide strong market entry for microfactory concept in the car production.

3.1. Sharing economy applied to the production of EVs

A microfactory can be made profitable within reasonable period in most regional-national contests due to the low investment needed. A further aspect to be considered is that the microfactory concept can be easily replicated in many regions. Because of that, a new perspective is opened: collaborative R&D&I (Research, Development and Innovation) on manufacturing.

The microfactory concept opens new routes in both manufacturing and business strategies. The product is conceived and assembled inside the factory. The supply chain for the critical components such as the motor/inverter, the tubular SHSS, the electronic board lights, the seats, the battery cells, etc. must be well established to be successful.

For newcomers, it may be difficult to penetrate suppliers for the large Tier1 OEMS. Multiple microfactory collaboration and negotiations with suppliers may transform their weakness into strength. Their collaboration again will help influence regulations on national-international standardization.

The possibility of replicating microfactories in different regions is also motivating large automation companies to contribute to optimize the manufacturing processes and to introduce advanced industry 4.0 technologies.

In summary the microfactory in different locations can be replicated with ease. Cooperative R&D&I among different microfactories minimizes the engineering cost while enhancing social sustainability in terms of local employment opportunities it can provide (Figure 3.1).

Every microfactory is to create its own brand customized to local demand. The collaboration with other microfactories will make these local brands stronger. In summary, this model of supply chain for the microfactory concept with cooperation of companies makes them stronger while they keep their entities economically independent.

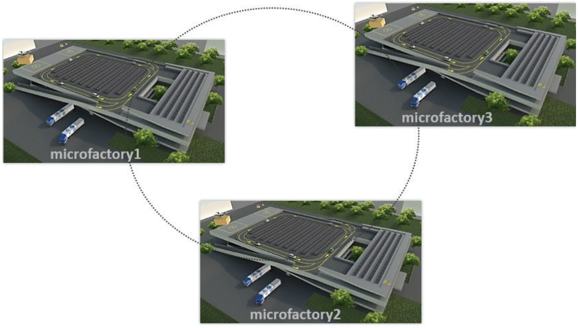

Figure 3.1 Cooperative R&D&I among different microfactories

3.2 Sustainability through Microfactories

Long-term success in the manufacturing sector requires achievement of four dimensions of sustainability, where three of them are known as Triple Bottom Line (TBL); economic, ecological and social aspects and the fourth one is political-institutional (Westkämper, 2008). Factories of Futures are aimed to meet TBL by combining high performance and quality, eliminating consumption and waste, integrating human skills and technology respectively. (EFFRA, 2021) Building a microfactory concept satisfies those dimensions in different degrees. The summary of sustainability dimensions is given at the end of this section (Table3.4)

1.Economic sustainability is fulfilled by the cost comparison such as the investment cost, the operation cost, the labor cost and the life cycle cost. The proximity to customer provides more customer satisfaction with more flexibility for customized products, which leads to more product value. Company may add special features according to region specifics or reduce features as necessary. The initial investment of constructing a microfactory and operating costs are significantly lower than Giga Factories, leading to a lower ROI. Depending on the battery technology, manufacturing of EVs is expected to become a cost-competitive alternative to ICE vehicles in the mid-2020s (Tsai & Champagne, 2016). Proposed microfactory model to produce EV economically feasible from investment to operation. For instance, in the current automotive industry, about 6000 components are used to produce a conventional ICE car. On the other hand, microfactory provides an alternative EV platform that simplify the assembly operations and could reduce the unit cost of vehicle up to ten times. In general, prototypes produced with pre-production by conventional technologies will cost above 100 M€, within the microfactory, the total cost of first prototype in early stage would be proximately 10 M€. Similarly, the breakeven point for conventional car manufacturing is 100000 units produced annually (Nieuwenhuis and Katsifou, 2015), while it is 10000 units for Microfactory to reach the breakeven point. A car was designed and produced in this study utilizing the proposed new manufacturing concept. The manufacturing of the model car by the microfactory method was studied in detail. Predicted key cost items are shown in Table 3.1 and the total production cost of one unit is estimated to be 10800 €.

Table 3.1 Cost estimation to produce an EV at the microfactory

Key components	Price, Euro (x1000)
Chassis (including cataphoresis)	0.4
Fully motorized axle (two axles)	2.6
Non motorized axle	0
Body panels	0.6
Rotomoulded Components	0.3
Glazing	0.25
Lighting systems	0.5
14kWh Battery system 2018	3.5
Steering system	0.35
Full Dashboard	0.6
Interiors	0.6
Others	1.1
Total Production Cost/prototype	10.8

2. Ecologic sustainability is satisfied by environmental sustainability indicators such as CO2 emissions, the air pollution, the energy consumption and the land use due to manufacturing and driving of vehicles. EVs reduce the transportation emissions by its design, while gasoline cars are heavily dependent on limited oil reserves. However, even though EVs have zero tailpipe emissions, on a well-to-wheel basis they are not GHG emissions-free. Nonetheless, increasing debate on electrification leads to some interesting future scenarios for 2030. It is clear from reports that the electromobility helps in massive reductions of green gas emissions and reduce the oil use in transportation (Europen Comission, 2009; European Roadmap, 2012; Tsai &Champagne, 2016; Cembalest & Morgan, 2018; Global EV Outlook, 2019). For instance, on a well-to-wheel basis, an EV produces 67% lower GHG emissions than an ICE car (Mackenzie, 2018). The technology and economies of scale for EV will offer better infrastructure and production techniques with recycling options due to simpler designs. EVs allow significantly lower GHG emissions through more renewable energy distribution and decarbonization of the electricity grid (Ellsmoor, 2019).

On a well-to-wheel basis, EV GHG projected emissions expected to be lower than gasoline powered cars. An average EV emit less GHGs (518 grams of CO2 equivalent per kilowatt-hour [g CO2-eq/kWh]) than an average ICE vehicle over their life cycle. However, it is important to note that CO2 emissions savings are much higher for electric cars when the power generation is dominated by renewable sources such as wind, water, photovoltaic, geothermal energy, biomass or animal waste. When the power generation mix is led by coal, then hybrid vehicles exhibit lower emissions than EVs (Global EV Outlook, 2019). Overall, EVs have lower emissions over their lifetime. The differences between ICE based conventional mobility and BEV in terms of CO2 emissions are summarized in Table 3.2

Table 3.2 Energy cuts comparison between conventional gasoline car and mid size BEV (Source: Perlo et al, 2009;Europen Roadmap,2012)

Conventional Mid size ICE Car		**Total CO_{2eq} emissions**
Well to Tank	**Tank to Wheels**	
35gCO2/km	140gCO2/km	175gCO2/km
Mid size BEV (150Wh/km)		**Total CO_{2eq} emissions**
*electricity produced by a modern plant of coal		127gCO2/km
*electricity mix 23%nuclear, 42%reneweable,35%fossils (EU-27 mix 2020)		41gCO2/km
*electricity mix 50% photovoltaic, 50%wind		<6gCO2/km

Moreover, EVs had more than 30% primary energy consume than ICE 20 years ago. However, recent years with the advance of technological developments, even if all electricity would be produced by fossils only, EVs can save >20% of primary energy used in the road transportion. Considering 38% of electricity produced by renewables the saving of fossil fuels in road mobility would in the range of 35% - 38%. The comparison between ICE and EV for use of oil in years is shown in Table 3.3. EVs offer a potential for primary energy savings by 30-40% and GHG reduction up to 67%.

Table 3.3 The primary energy consumption of EV and comparison to conventional powertrain (Meyer et al,2017).

Year	**Power Plant Efficiency**	**Grid Effic.**	**Charger AC/DC Effic.**	**Battery Effic.**	**Inverter DC-AC Effic.**	**Motor Effic.**	**Energy consumption ideal mid-size car Wh/km**	**Total consumption of primary Energy Wh/km**
EV 2000	0.39	0.88	0.85	0.70	0.88	0.80	120	954
EV 2017	0.48	0.94	0.95	0.94	0.95	0.90	120	348
ICE 2000	Powertrain efficiency of a conventional ICE car 0.20 (including transmission)						120	600
ICE 2017	Powertrain efficiency of a conventional ICE car 0.25 (including transmission)						120	480

In addition, the plants for the microfactory can be designed to be energy independent by the use of solar panels integrated with batteries for continuous clean power that result in a cleaner production.

3. Social sustainability is fulfilled with the truth that the work steps by human operators are simpler, even if microfactories are highly integrated with digitalization. Industry 4.0 supports local manufacturing since it also shifts the production from the offshore country to the homeland, as low labor costs are no longer an advantage. Although conventional automotive industry has higher social benefits in terms of employment rate, tax and compensation, microfactories have potential to compete with it with smart manufacturing advantages. The local manufacturing creates new job opportunities as smart manufacturing differentiates itself from other initiatives with the specific emphasis on human integration into this data-driven, connected system (Thoben et al, 2017). Human operators are more flexible to respond quick changes in the product and market (Michalos et al, 2010), therefore they are still more convenient in specific areas (e.g microfactories), and on the other hand, robots for instance are used to perform dangerous and difficult tasks instead of human, with high level of accuracy, speed and repeatability thanks to the Industry 4.0 infrastructure (Villani et al,2018). Therefore, both robotized manufacturing (Pham, 2020) and e-mobility favor the human health and safety risks in high degree compared to ICE vehicles (Onat et al, 2019). Therefore, a smart process design with human-machine integration is key to future success.

4. International environmental policies push governments towards sustainable manufacturing to decrease pollution due to manufacturing processes and operation of vehicles. For instance, EU plans to reduce GHG emissions by 80-95% by 2050 by increasing the use of EVs powered by renewable energy sources (EEA, 2016). Therefore, most countries are planning to become fossil fuel-free on the road by 2050 (Petroff, 2017). The French government propose up to 2,500 euros incentive to switch to a less polluting vehicle (Reuters, 2017). Costa Rica plans to become fully decarbonized by 2050 and zero emission public transportation by 2035 with removing gasoline and diesel from road (Hickman, 2019). The Asian countries are aiming to completely phase out petrol and diesel cars in favor of EVs (Dugdale, 2019). The effective policy mechanism is investigated for Nordic region (Kester et al.,2018), concluded that price incentives combined with local flexibility to implement secondary benefits such as tax allowance, charging infrastructure support and awareness campaigns are needed to encourage the adoption of EVs. Norway is one of the leading countries in BEV adoption, many tax and other incentives exist such as the exemption from roadway tolls with charging infrastructure and right to use of bus lanes in traffic (Mersky et al., 2016).

The importance of industrial policies is analyzed for the case of Turkey and South Korea (Yülek et al, 2019). Authors reported that the difference in the industrial policy framework and ecosystem leads, Korean auto sector has outperformed its Turkish counterparts by a large margin although they have similar conditions at the beginning. If incentives by governments increase for EV production as well as EV sales, the current monopoly could be broken by the use of microfactories. Microfactory with the government incentives is feasible to satisfy institutional sustainability.

Microfactory also fulfills sustainable manufacturing on the basis of lean manufacturing and Industry 4.0 infrastructure. As first introduced by Ohno (1988), seven traditional wastes (Muda in Japanese) commonly occur in manufacturing systems are over-production, the transportation, the motion, waiting, the inventory, unnecessary processing, and defective parts. It has been reported by Satoglu et al, the common focus of both lean manufacturing and industry 4.0 are decentralized structures and small, easy to integrate modules with a low level of complexity. The term lean automation, applying Industry 4.0 technologies into Lean Production, suggests making automated the repeating and value-adding tasks. They propose the Industry 4.0 technologies to achieve lean production. For instance, using 3D printing and IoT, reduce the lead time of products and decrease the waste of waiting, the inventory, unnecessary processing, overproduction, and defective parts. (2018). As an important feature of smart factories, adaptive robotics eliminate or minimize the waste such as the transportation, the motion, waiting, processing, and defectives.

The proposed microfactory concept is a lean production method which eliminates most of waste and redundancies in the production process. For instance, overproduction occurs in mass production due to the push systems, while production in microfactory starts with a customer order. Waste of waiting due to the tooling is also prevented in the microfactory concept since it eliminates die and moulds in production. In addition, a highly distributed, localized production system integrated with smart technologies proposed by microfactory eliminates the transportation waste, too.

Table 3.4 Comparison of manufacturing methods according to sustainability advantages

Manufacturing Methods in Automotive Industry	**Sustainability Advantages**	**Disadvantages**
Conventional car manufacturing **key elements:** ➢ **ICE** ➢ **BIW**	**Social**: Few sustainability advantages in terms of creating jobs, because car-manufacturing companies have already employed huge amount of workers. **Institutional**: Government funding currently support existing OEMs.	**Ecological**: Mass production and complex operations consume higher energy and create higher GHG emissions. **Economic**: Higher capital investment and high technology & knowledge required. **Social**: Employee profile includes mostly high-skilled people.
Microfactory **key elements:** ➢ **Powertrain** ➢ **Tubular chassis**	**Ecological**: While EVs reduce emissions on the road, lean manufacturing minimizes operations, reduce waste and save energy. **Social**: Opportunity for emerging country to have a domestic brand, Opportunity for new entries to automotive industry. Use of human operators is still profitable, More localized employment. Major favor in human health. **Economic**: Traditional cost barriers broken down. Much more flexible system compatible with dynamic market demand. Lower cost of entry and exit. Suitable for low volume innovative product. **Institutional**: Traditional access barriers can be broken down with government incentives.	**Economic**: initially may not be competitive with global manufacturer. Difficult to reach Tier 1 suppliers as a new comer. A specific supply-chain model should be applied.

4. Results

4.1 The Microfactory Concept: preliminary analysis

Because of the approach adopted in this study, the welding robots are not needed. The automation and control of all processes are made with affordable and easy to use digital technologies. Automated guided vehicles (AGV) is used to move the parts from one working island to another. The each microfactory manufacturing flow is designed to produce 50 vehicles in 2 shifts per day (Perlo and Tebaldi,2019) under the hypothesis of 10 automated islands and two testing areas, and all the production processes explained in section 4.1.1 are performed inside this factory. Manufacturing line of microfactory to produce electric vehicles is illustrated in Figure 4.1.

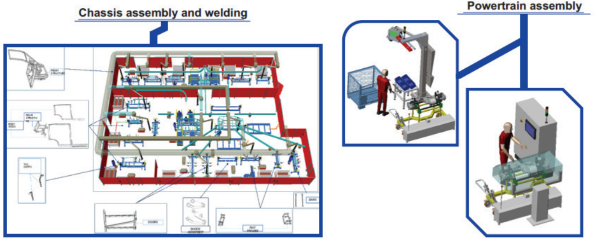

Figure 4.1 Manufacturing line of EV in microfactory designed by I-FEVS ((Perlo and Tebaldi,2019)

When the estimation of the desired production has been taken as input, the line cycle time of producing one unit electrical vehicle at microfactory is calculated at the following Table 4.1:

Table 4.1 The feasibility study shows the manufacturing cycle time at the microfactory.

Jobs per Day (JpD)	50 units
Shift days	2
Shift Length	7,5hours
O.E.E (desired overall equipment effectiveness)	85%
JpShift	50/2 =25
JpH Gross (ideal)	25/7.5=3.34
JpH Net (O.E.E included)	3.34/0.85=3.93
Cycle Time	3600/3.93 =916 sec.

The cycle time of one unit of EV is 916 seconds at microfactory, while it is approximately 60 seconds for conventional automotive plants.

4.1.1 Layout

The layout of the microfactory for EV production is shown in Figure 4.2. The main production modules are arranged according to the order of the production process to optimize timing between operations. The center of the production area is the storage of components and materials to provide quick support the assembly modules. The order of operations inside the microfactory is given below in detail.

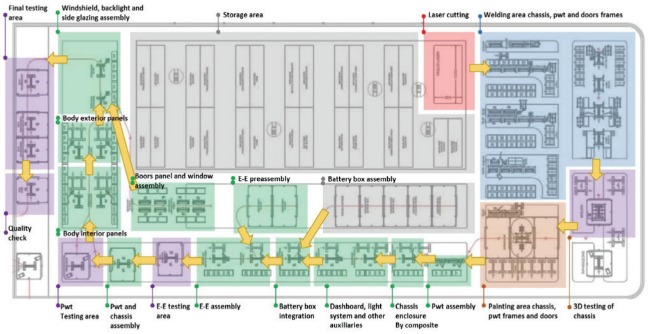

Figure 4.2 The Layout of a Microfactory for EV where the operation starts from laser-cutting stations (in red) and ends with final quality checks (in violet)

Laser cutting, the red zone in Figure 4.2, is the first part of the production process. In this area, the SHSS tubulars are laser-cut with a CNC automated machine as shown in Figure 4.3.

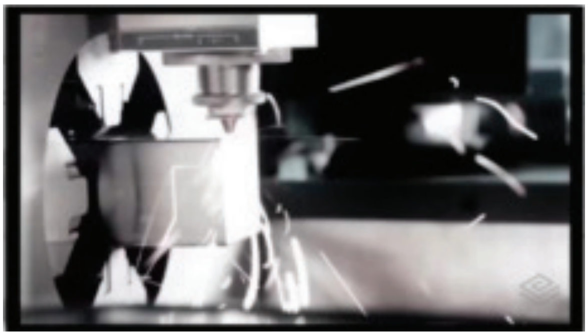

Figure 4.3 CNC automated Laser-cutting of chassis tubulars

The next part in the microfactory is welding area for chassis, powertrain and door frames. This area receives the laser-cut SHSS tubulars and output the complete chassis, the two powertrain axles and door frames ready for the geometry checks before painting. The floor sub-frame assembly module oversees the production of the central part of the underbody that, once completed, will host the battery pack. The front sub-frame assembly is the module that produces the last part of the underbody of the car. The upper sub-frame assembly is fabricating the upper part of the car frame. The framing geo welding module combines the lower and the upper subassembly frames. The output is a complete welded frame ready for the final 3D measurements and checks before painting.

3D testing of the chassis is a module for an intermediate quality control area. It validates the chassis, measuring its geometry and comparing results with the expected values and tolerances. If the result is positive, the chassis is ready for painting.

The operations continue in painting area, the brown zone in Figure 4.2. The painting area oversees painting and giving the proper protection to the complete chassis the two powertrain frames and the doors structures. This is the last step before starting the final assembly of the car.

The powertrain assembly operations shown in green in Figure 4.2, produces the front and the rear axles. Motor, drive, gearbox, shock absorbers, brakes and wheel hubs are assembled on the painted powertrain frames. There is axle system test module where motor and inverter are paired; several figures of merit, related to the type of electric motor and its integrated position sensor, are setup. Once the mechanical part of the vehicle is ready, the battery box is added, together with the electrical and electronic (E-E) items and connections: all the control boards and the wiring are installed.

The overall performance of the powertrain is tested in Powertrain testing area with a 4WD (4-wheel-drive) Chassis dynamometer. It consists of a rolling test-bench which fulfils the stringent requirements to test high power heavy vehicles as well. One of the latest phases of the vehicle assembly is the installation of the exterior panels. In this stage, the car takes its final look.

4.1.2 Factory system architecture

A top-down approach is applied to identify the relevant requirements and their relation to the key performance indexes (KPIs).

The platform consists of a Manufacturing Execution System (MES) that contributes to the following tasks:

- Production scheduling
- Traceability of production
- Traceability of used materials
- Control of the production flow
- Visualization of the KPIs.

Human roles are carefully considered, and associated requirements are identified for the MES user interface (UI) and the human machine interface (HMI). Figure 4.4 shows process links with application services that handle the scheduling, traceability, materials tracking, control of the production flow and the KPIs. MES processes orders entered on the web via middleware, and scheduler plans services to optimize the production visible though the internal application specific to the relevant production steps. Apps trace the materials and provide traceability during the work flow. Working islands developed provide feedback from identification sensors and HMI, monitored by the appropriate App. Tests are performed on sub and complete systems, results are fed to the MES to the appropriate App.

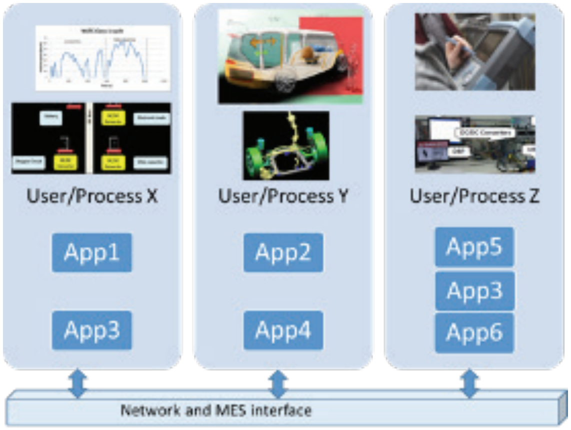

Figure 4.4 A schematic representing the dynamic monitoring process, middleware and MES user interface (UI)

4.1.3 Human interfaces

The possible scenarios in the flexible production systems for human support are Human-in-the-Mesh and Human-in-the-Loop (Table4.2).

Table 4.2 Two scenarios for human machine integration Human-in-the-Mesh and Human-in-the-Loop

Human-in-the-Mesh requirements on HMI	**Human-in-the-Loop requirements on HMI**
Context-aware mobile devices	Context-aware mobile devices
Intuitive representation of alternatives and trade-offs	Visual inspection with sensors
Decision support enhanced by AI	Testing (geometrical, power train, fatigue, etc.)
	Virtual presence: sharing view, screen, info, voice connection or chat
	Multimodal interaction (voice, image, gesture recognition, sounds, lights, etc.)
	IoT -Suitable/wearable device to support field-work
	Asset tracking (tools and spare parts)
	Navigation to retrieve machines, tools, spare parts.

The factory system architecture is shown in Figure 4.5. MES processes orders (submitted manually or on the web), monitors and visualize KPIs, and scheduler plans services to optimize the production. Working islands consist of feature part identification sensors, feedback lights and HMI. Finally, testing area is place where tests are performed on sub and complete systems, results are fed to the MES.

IO-Link is a powerful standard for point-to-point serial communication protocol to use sensors and/or actuators. Well-known PLC standard IEC 61131 enables three types of data exchange; process data, service data, and events. The I/O link Master monitors all the sensor of the working island. Every island has a dedicated HMI. The workflow is shown in Figure 4.6.

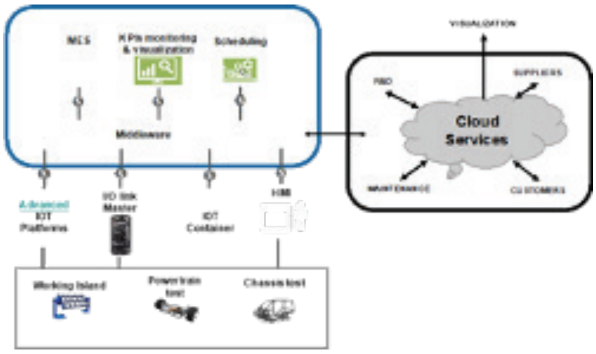

Figure 4.5 Factory system architecture

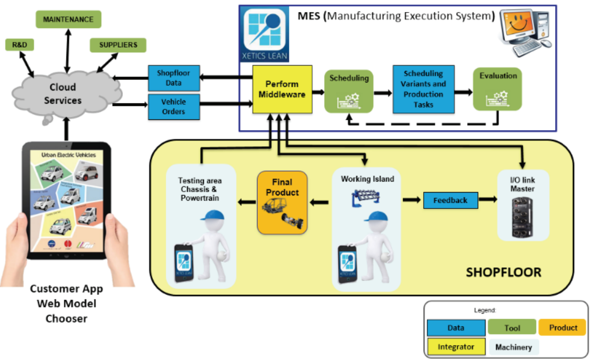

Figure 4.6 Workflow

5. Discussion

In this research, a factory model that conforms to Industry 4.0 model is designed, which saves the automotive sector from die dependency, expensive tools, and investment costs. It can, therefore, be assumed that utilizing automotive assembly line manufacturers will enable market entry for microfactory concept.

A SWOT analysis for the described microfactory concept can be summarized as follows: Strength; this concept provides product variability with minimum cost, platform flexibility for specific local needs, greener production with lean processes, and competitive advantages with low investment.

Weakness; the current supply chain is already under control of a few large OEM's. Since the microfactory produces in small scale compared to giga factories, it is difficult and costly to reach Tier1 suppliers for this relatively small lot sizes. Therefore, a weak supply chain infrastructure can lead to a high distribution cost. To overcome this weakness, microfactories should establish a network, the microfactory concept performs its best when replicated in different locations. Another weakness of this model would be the difficulty of making negotiations among replicated parties at the initial stage.

Opportunities; both the production concept and the final product, have high potential to meet increasing electromobility demand. Although ICE based automotive industry is captured by a few pioneers over a century, EV market have still place to the newcomers. Moreover, micro EVs have also potential to meet urban mobility needs such as provided by MaaS platforms. EV produced in microfactory has also opportunity to satisfy sustainability dimensions in different degrees, as summarized in Table 3.4.

Threats; there is always high rivalry in automotive manufacturing industry. Since the microfactory concept is relatively new, gaining the government support and persuade the investor might be difficult at the beginning. A weak supply chain is a threat which results in a high distribution cost. Therefore, the establishing a well-defined supply chain is crucial for the components such as the motor/inverter, the tubular SHSS, the electronic board, the lights, the seats, the battery cells, etc. to secure the supply chain. A further study with more focus on blockchain integrated supply chain is therefore suggested.

According to the business model in this study, the replication of microfactories creates a globally distributed network. To succeed in this highly distributed network, today a central authority is required which is not desirable in this network as it is explained by sharing economy. Therefore, the challenge of this model is the safe journey of data among network participants without intermediaries. However, implementing blockchain technology might be a solution to provide trustable transactions peer-to-peer by the effect of collaboration and cryptography without a third party. (Korpela et al., 2017). This yields that all transactions will perform between involved microfactories and engaged suppliers, without the need of a central authority to control and manage the system. The data of all microfactories distributed across a global ledger, using the highest level of cryptography. Thus, the secure model offered by blockchain technology, can also be adaptable to the microfactory network, in our earlier study (Dursun et al, 2020). In the microfactory network, there exist the smart contract between parties which allows to each party programmatically define the rules and steps that should be performed when a certain type of event is recorded in the blockchain or in the magic notebook. As a result, the proposed business model for microfactory networks has parallel with blockchain technology since it is a simple way of passing information in a fully automated and safe manner without the need for intermediaries.

According to sustainability analysis, these results provide further support for the hypothesis that microfactories fit the cleaner production elements as for instance the total amount of components to produce an EV decreased from approximately six-ten thousand to three thousand. In addition to that, cleaner supply chain is suggested. As microfactories create new job opportunities and favors public health, reduce CO2 emission, the energy waste and the air pollution from manufacturing process and driving of vehicles, an implication of this is the potential that the microfactory satisfies sustainability dimensions in different degrees.

6. Conclusion

This study proposes a novel design for manufacturing electric vehicles through microfactories, enabling customized production of EVs with minimum ecological footprint and the total investment. The production of BIW and ICE are two main obstacles for newcomers, the operation process includes complicated steps of stamping and components to the assembly, which requires high capital and technical skills. Conventional techniques require large-scale production to reach desired ROI and here proposed microfactories can potentially break this closed-loop monopoly between OEMs-TIERs-governments.

Electric powertrain challenges the ICE, and the tubular chassis challenges the serial welding assembly line with the stamped metal sheets, the sharing philosophy is recommended among microfactories to overcome the supplier monopoly and to attract government subsidies. The microfactory concept developed here makes several noteworthy contributions to sustainable production in case of manufacturing electric vehicles.

This work is being further discussed with collaborators from the industry and academia in local market and internationally to develop an application specific prototyping of a shuttle for transportation and/or logistics. An autonomous shuttle project from design, software including AI (Artificial Intelligence), AR (Augmented Reality) user-interface inputs and autonomous transportation service routing aspects is currently under study for a smart-city application.

Acknowledgements

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