MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

THE ASSESSMENT OF MICROFACTORY CONCEPT TO MANUFACTURE NEW GENERATION ELECTRIC VEHICLES

BÜŞRA ALPTEKİN

MASTER THESIS
Department of Industrial Engineering

Thesis Supervisor
Prof. Dr. Bahadır TUNABOYLU

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Declaration of Authorship

I, Büşra Alptekin, declare that this thesis titled, 'The Assessment of Microfactory Concept to Manufacture New Generation Electric Vehicles ' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
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The Assessment of Microfactory Concept to Manufacture New Generation Electric Vehicles

Büşra Alptekin

Abstract

The electromobility presents a potential for nations to develop and produce their domestic cars especially for emerging markets. This thesis proposes a new concept, called microfactory, for manufacturing new generation 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. In this study, the current automotive industry, which depend on the conventional technologies and its drawbacks described. There are three main de facto monopoly in the automotive industry are addressed; the first two of them, 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. Therefore, the microfactory represents an alternative solution to overcome the existing monopolies with the electric motor, a tubular chassis, and novel business model respectively. The new opportunities with electromobility trends and its potentials to create new ecosystem is presented for countries who want to produce its domestic car. A detailed analysis of the difference between conventional techniques and new production paradigm is also presented in in terms of sustainability dimensions and cost perspective. In particular, the principles of 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 a low investment. The aim of this paper is to propose a new disruptive manufacturing method that allows a quicker entry for new players in automotive industry especially for EVs.

Keywords: automotive industry, advanced manufacturing technology, electric vehicles, flexible manufacturing, sustainable production, microfactory

Yeni Nesil Elektrikli Araçların Üretimi için Mikrofabrika Konseptinin Değerlendirilmesi

Büşra Alptekin

Öz

Bu tezin öncelikli amacı, sayıca az büyük otomotiv üreticilerinin tekelinde olan sektöre yeni bir üreticinin girmesine olanak sağlayan alternatif bir üretim konsepti sunmaktır. Mikrofabrika konsepti ile içten yanmalı konvensiyonel araç üreticilerinin domine ettiği sektörde yeni nesil, elektrikli konsept araçların üretimi için kobilere ve kendi yerli otomobilini üretmek isteyen ülkelere rekabet edilebilir bir model sağlanmaktadır. Literatür çalışması kapsamında local üretim, dağınık üretim sistemleri ve bunlara bağlı olarak mikrofabrika teriminin literatürdeki karşılıkları analiz edilmiştir. Bu tezde sunulan konseptte literatürden farklı olarak elektrikli araç üretimi için yeni bir mikrofabrika yöntemi tarif edilmiştir. Son yıllarda, elektromobiliteyle birlikte artan yeni trendler ve bunların sağladığı imkanlar öne çıkarılmıştır. Konvansiyonel teknikler ile yeni üretim paradigması arasındaki farkın ayrıntılı bir analizi yapılmıştır. Bu çalışmada, mikro-fabrika ilkeleri, yerleşim planından, operasyon aşamalarına, mikrofabrikalar için paylaşım ekonomisine dayanan tedarik zinciri yönetimden iş planına kadar detaylı bir şekilde incelenmiştir. Önerilen yöntem sürdürülebilirlik açısından da değerlendirilmiştir. Özetle bu tez, 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 Sözcükler: otomotiv üretimi, elektrikli araçlar, sürdürülebilir üretim, akıllı üretim, esnek üretim sistemleri, mikrofabrika yöntemi

dedicated to my parents . . .

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Abbreviations

4WD	**4** **W**heel **D**rive
KPIs	**K**ey **P**erformance **I**ndicator
MES	**M**anufacturing **E**xecution **S**ystem
UI	**U**ser **I**nterface
HMI	**H**uman **M**achine **I**nterface
MaaS	**M**obility **a**s a **S**ervice
R&D&I	**R**esearch **D**evelopment and **I**nnovation
SHSS	**S**uper **H**igh **S**trength **S**teel
TBL	**T**riple **B**ottom **L**ine
ROI	**R**eturn on **I**nvestment
ICE	**I**nternal **C**ombustion **E**ngine
BIW	**B**ody in **W**hite
BEV	**B**attery **E**lectric **V**ehicle
EV	**E**lectric **V**ehicle
PHEV	**P**lug in **H**ybrid **V**ehicle
OEM	**O**riginal **E**quipment **M**anufacturer
GHG	**G**reen **H**ouse **G**as
AGV	**A**utomated **G**uided **V**ehicles
PSS	**P**roduct **S**ervice **S**ystem
TUT	**T**ampere **U**niversity of **T**echnology
DMS	**D**istributed **M**anufacturing **S**ytems
SKD	**S**emi- **K**nocked- **D**own
CKD	**C**omplete- **K**nocked- **D**own
SME	**S**mall **M**edium **E**nterprises

Chapter 1

Introduction

1.1 Motivation

The history of electric vehicles is based on the early 20th century, but technology at that time was poor to win against gasoline cars, which were more affordable, cheap and available. However, 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 includes the redesign of vehicle manufacturing platforms using simpler and innovative design architecture, and the application of big data to right size batteries [1]. 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 best for the environment with almost zero emissions in traffic, environmental and investment issues related to their manufacturing processes are still a concern [2]. Therefore, new manufacturing methods to produce environmentally friendly, reliable and affordable EVs are needed. There is also electromobility trend towards autonomous vehicles with high security capabilities. The environmental policies such as Kyoto protocol promote the transformation process from Internal Combustion

Engine (ICE) to electric motors for the automotive industry to reduce world's CO2 emissions.

Although many improvements in EV technology in terms of performance, efficiency, styling, availability and demand are increasing daily, EV remains more expensive to manufacture. Thus, manufacturers looking for new production methods. Therefore, it is expected that the future factories should be smarter in order to quickly respond to customer requirements, maintenance services for unseen failures, and allow quick retrofits [3]. 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.

1.2 The Current Automotive Sector

The automotive industry is a 'locomotive' sector for the whole economy since it is highly correlated with other industries in the economy. For instance, the automotive industry is the major buyer of iron-steel, petrochemical, and tire industries and the driving force behind the technological developments in these industries. This sector produces all kinds of motor vehicles needed by the tourism infrastructure, transport, and agriculture. Therefore, any changes in this industry directly affect the economy. The automotive industry 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 [4].

On the other hand, the existing automotive sector is heavily depend on conventional productions, which requires high technical skills and capital. As a result, the sector captured by a few large OEMs, and small manufacturers usually have to be sold to its big rivals or have to establish a joint venture to survive in the market. The graphical representation of the current system as how only fourteen giant car companies dominate the global automotive sector is given in Figure 1.1 [5]

It is reported that these corporations due to the 'solidarity' is necessary to cope with the challenges arising from the global economy and for a sustainable ecosystem. The one



FIGURE 1.1: The few number of companies dominate the global automotive sector [5]

recent examples in terms of both sector dynamics and orientation towards future collaborations are, Ford and Volkswagen decided to manufacture their electric and autonomous vehicles at each other's factories in 2018. Volkswagen has also agreed to produce its commercial vehicle Crafter and Transporter at the Gölcük plant, where Ford Otosan produces Transit and Custom.[6]

At the last decade, the concept cars in the technology fairs show that the car is not only a means of transportation, it is consolidated with different technologies, and it turns into a technological and smart device. The top five trends in 2019 listed as connectivity and digitalization, electrification and mobility, vehicle sharing, autonomous self-driving vehicles, and market growth in developing countries. These "Mega trends" are expected to shape the future of the global automotive industry. Moreover, electric vehicles have

already growing its market [6, 7].The 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. 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 [8]. Moreover, China remained the largest growth contributor, with 1.2 million EV sales, which are 56 % of all EV sales in 2018. Plug-in vehicle sales -include all Battery Electric Vehicles (BEV) and Plug-in Hybrids (PHEV), passenger cars and light commercial vehicles- in Europe 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, 8].

1.3 National Vision

Automotive industry has an important role in Turkish manufacturing sector as well as other industrialized countries. The amount of motor vehicle produced in Turkey per year is around 1.5million units since 2016. Turkey became 5th largest automotive producer in Europe and 14th in the world [9]. However, even though Turkey has important lot in car manufacturing sector, it has not its own car brand to produce Turkish car until now. The car manufacturers in Turkey are mostly global car manufacturers who use decentralized production strategy and put production plants in emerging markets with respect to effective factors and they produce some products for local markets. These are Hyundai, Toyota, Honda and joint ventures with the Turkish companies Otosan, Oyak and Tofas, which are called Ford/Otosan, Oyak-Renault and Tofaş/Fiat [10]. In addition, there are other Turkish companies, who produce semi-finished products or spare parts for car markets as subsidiary industry. Moreover, these manufacturing plants are mainly located in European side of Turkey and therefore automotive industry has clustered in Marmara region. To manufacture its own national automobile was Turkey's dream since 1960s, and Devrim cars became the first attempt to produce a domestic car with the government incentives. There were only four prototypes produced but project was stopped, besides there was no production plant or even an assembly line like Toyota, and research and development infrastructures was not sufficient in that time. Then, the first mass produced domestic car became Anadol, which is designed as low cost

and suitable for middle class by Ford Otosan. Still, Anadol was not 100% Turkish brand, and it had no value added in global markets. Due to the quality issues and increasing demand for international brands, this project ended late 70s. Since then, other joint ventures and global manufacturers have been established their production plants at Marmara region and produced localized models for Turkish customers [11]. For the purpose, the government incentives has been started to produce the first domestic car, Turkey's Automobile (TOGG). According to TOGG, although the studies are still at initial phase, it has been finalized that Turkey's first domestic car will be an electric vehicle. The recent data of EV passenger cars production in Turkey as follows, Ford Otosan 25K, Honda 25K, Hyndai Assan 178K, Tofaş 160K, Toyota 252K units for one year [12].

Since the automotive sector in transition process from conventional vehicles to hybrid and electric vehicle technologies, technologies such as battery technologies, electric drive and control systems, smart transportation technologies and advanced driving support systems are demanded in future vehicles. For Turkey, which is quite late in creating its own brand in conventional vehicle production, this new technology in automotive has once again opened up an opportunity to create its own brand and become a strategic player in automotive. Therefore, domestic car project is also a technological leap and catching the Industry 4.0 revolution. In the fields, such as battery technologies, electric drive and control systems, smart transportation technologies, advanced driving support systems etc. it is also important for emerging countries who want to enter this EV manufacturing market like Turkey, to have knowledge and ability to develop these strategically important technologies locally. The targeted national vision should be:

- Creating a global Turkish automobile brand
- Reducing foreign dependency in oil
- To produce the battery locally since it is the main cost element of EV
- To produce low emission environmentally friendly vehicles
- Having a say in the technological change process in the automotive industry
- To ensure the future of the Turkish automotive industry and to become a strategic player, not a supplier industry.

- To develop critical sectors such as defense, electronics, information technologies and smart grids with the ecosystem created by the domestic production of technology.

The existing gasoline monopoly includes large size production required to decrease unit cost, to have large product variety, to have distributed market, but small manufacturer could not compete. At least it is too late and impossible to compete in gasoline cars. However, Turkey has there is still chance for Turkey to catch with its background and experience since the EV market and technology is still new for everyone. Turkey has technology and infrastructure capability to produce. To enter this new era, a competitive business model required, variety of product spectrum, customized perspective are required for new comers. In addition, government support are important for instance, China, USA and Europe governments support EV sales with special incentives.

In this study, a microfactory is introduced to develop national vision for emerging countries to address smart and innovative manufacturing model to produce an EV as an alternative manufacturing method that enables sustainable production. For the purpose, a detailed literature review is done to give high-level background about new trends in EV, battery, 3D manufacturing in literature and taxonomy for distributed manufacturing is given. With the summarizing literature about the key terms of this thesis, 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 second to last section, the blockchain technology is discussed to develop a microfactory supply chain for future study.

Chapter 2

Literature Review

2.1 Taxonomy of Distributed Manufacturing

The manufacturing distributions identified through literature review are summarized in Figure2.1[10]. Distributed manufacturing is categorized as DIY, artisanal and industrial, and each of them has three sub categorizes. DIY manufacturing is divided into three waves[13, 14] : 1st Wave DIY (subsistence) is that the people produce what they consume. 2nd Wave DIY (industrial), people buy semi-produced kits from companies like IKEA and make final assembly at their home. 3rd Wave DIY (post-industrial) is mainly related to terms maker movement, FabLab, social manufacturing..etc, and it consist digitally-driven design/manufacture, to provide an opportunity normal people to create, design, make, and/or sell goods what they imagine, Etsy.com can be given as an example. Artisanal manufacturing includes rural, which is a craft-based manufacturing of specialty cheeses, carpets, etc., manufacturing at retail outlets such as patisseries, tailors, etc. is categorized as urban, and manufacturing of easily posted goods by Web shops, is called as Web in this taxonomy. Furthermore, under the industrial distributed manufacturing parts is for manufacturing of components; (S/CKD) represents semi knocked-down kits and complete knocked-down kits. Unlit is another subcategory of industrial distributed manufacturing and it considers the complete goods such requires high technological infrastructure and high automation. Since the human operators are not much needed in this type of manufacturing, this is also called as dark manufacturing,and mostly SMEs with special technical skills can operate in this category[10]. Centralized manufacturing includes current conventional production units such as Giga factories.

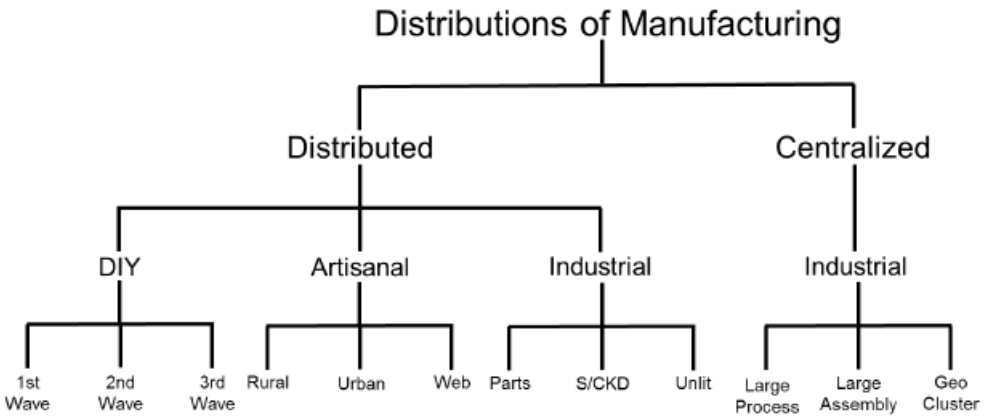

FIGURE 2.1: Distribution of manufacturing [10]

The tripple bottom line (TBL) sustainability level for the taxonomy of distributed manufacturing is described in Figure 2.2 [10] The 1st Wave DIY has high probability in sustainability dimensions, except for economic dimension since people make products for themselves. The 3rd Wave DIY has high potential in terms of social sustainability and medium potential in other dimensions. Industrial distributed manufacturing is economically and socially sustainable.

Emerging markets is an optimistic term for growing and developing countries, which previously may have been referred to as 'non-developed countries' or 'less-developed countries'. The largest emerging economies are referred by the acronym 'BRIC' countries, which encompasses Brazil, Russia, India and China. Over the past two decades, sustainable production has become an increasingly important issue for BRIC countries and for other emerging markets. It has been argued that distributed manufacturing(DM) can make an important contribution to achieving this aim. However, although there is extensive literature about decentralized manufacturing, the term remains vague and hence indeterminate.

At the highest level of abstraction, production strategies as follows: centralized, combined and decentralized. Centralized production system can involve the full scope of operations, including R&D, procurement, production and sales, being carried out in one part of one country. In combined strategy, operations can be done in both a company's home country and in host countries where there may be raw materials, production units and/or sales

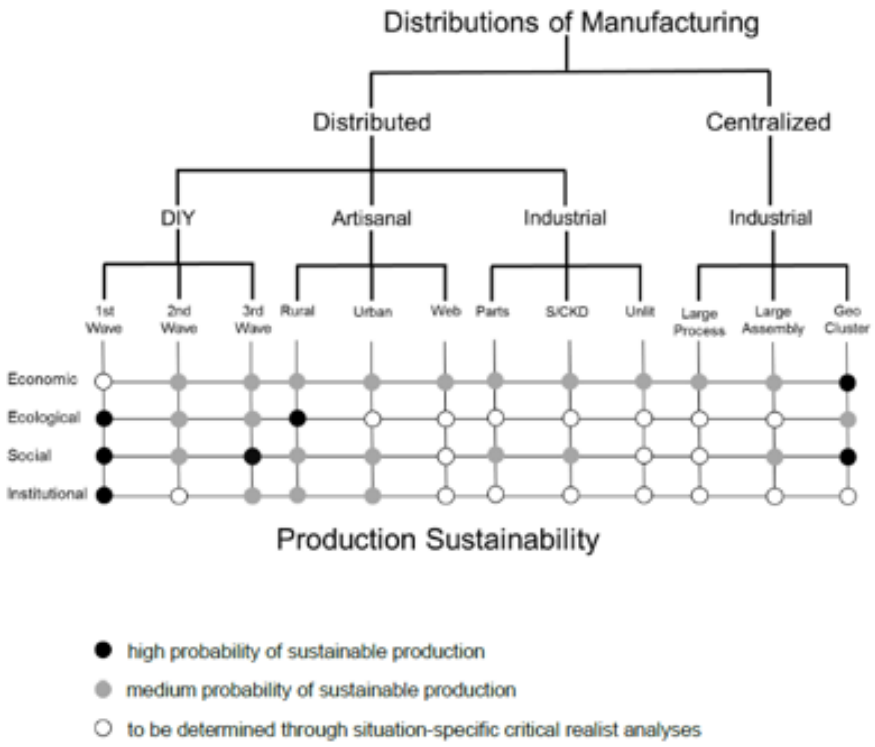

FIGURE 2.2: Sustainable production taxonomy [10].

centers. This strategy can involve complex transportation networks, which span several continents. This combined manufacturing system involves some distribution, but may contribute little to improving sustainability. A higher level of decentralization involves there being no constant company transportation link between home and host countries; with every site being able to deal with all of production steps from procurement to sales by itself.

An important consideration is whether distributed manufacturing is conceptualized as being highly distributed globally or highly distributed locally. Clearly, many of the biggest global companies have been using decentralized production sites in those emerging countries for decades, which can provide benefits to them such as; proximity to market, low transportation cost, and low labor costs. In some cases, they have taken into consideration local tastes by having production processes flexible enough to meet local customer requirements. Nonetheless, there is still at least a headquarter in home country and centralization still exist in many management process. On the other hand, this level of production distribution is small compared to the independent production operations of local manufacturing carried out by, for example, family owned blacksmiths,

patisseries, and tailors. They are usually located according to demand and save local tastes or customization is highly suitable, basic and sometimes specific labor skills are enough for production.

Another consideration is what type of goods can be produced as distributed? Goods which have continuous production process may continue to be best suited to centralized production. This can be because of the inherent value of materials, e.g. gold; the inherent danger of materials, such as plutonium, the heat and pressure needed to process materials such as iron ore and crude oil. By contrast, more assembly operations may have potential to be carried through highly distributed local production due to the introduction of machines such as 3D printers that can carry out the work of several traditional machines. Nonetheless, there are also arguments for centralizing 3D printing. Make-to-stock goods can also be produced with globally distributed manufacturing because company may tend to emerging markets due to low cost and increasing demand with respect to local needs. Company puts its factory where the demand exist and this local factory produce those customization goods under the standardization of company brand.

The different strategies in car manufacturing is reported according to comparison between Volkswagen and Toyota [15]. According to that, the new emerging markets, competition due to cost pressures, economic situations such as fluctuating exchange rates and increasing oil price, and industry-specific requirements that is new car concept with low cost and environmentally friendly technologies are external factors, which affects international value chain. These factors lead to companies restructure the configurations units as decentralized or centralized. For instance; downstream value activities, such as marketing, sales and service, should be locate where customer exist (decentralized), others except HR centralized at limited place. Car producers initiate foreign subsidiaries by building production and sales unit in local markets. Major car companies have joint venture with Chinese companies, to put their production sites in China and operate under Chinese law which Volkswagen group miss this point. Because Volkswagen Group even if they set their production sites in some degree distributed, their operations still depend on home country, German standards. Volkswagen sells its vehicles to 150 countries while it has 48 production sites in 19 different countries, however a few years younger competitor, Toyota reach 170 countries in market while it has 74 production facilities in 27 countries with more decentralized network. For both, the highest production and sales rate are in their home regions. Even though Volkswagen has production facilities in different

countries, the reason why they are not so much distributed is, it has no production units in every market. For instance, one of the biggest car market US, Volkswagen Group has no production. In addition, relation between production sites and sales rates shows that the place where you do not manufacture in it, you sell less than your competitors do. Even if you think global, you have to produce local as well. For US market, Volkswagen vehicles' price higher because of the fluctuating exchange rates while producing in Europe and selling in US. Competitors, which have plant in US, have chance to decrease effects of unstable exchange rates and transportation cost. Another important reason why Volkswagen lagging behind Toyota and others in global market is, its products are not customized according to local taste of respective markets because it has no R&D units in there to know the customer expectation. Because, Volkswagen R&D units are mostly located in Europe, on the other hand, Toyota' research units are in its home region but it has development units, which are distributed as its production plants [15]

Car manufacturers use centralized strategy to achieve critical mass, advantage of economies of scale and learning effects and economies of scope. This brings benefits such as easy access to information, communication, no cultural, and language barriers, quickly completion. Since information remain in one site, maintain confidentially is easier, establish largely uniform culture, avoid conflicts between employees in different sites. Besides, decentralization strategy is used for working with qualified personnel, comparative cost advantages. Companies distribute the risk while increasing flexibility and innovative capacity to meet the local customer demand with more product variant. The government of a host country also provide support for this global company's investment. Decentralized strategy is usually chosen to overcome logistic barriers as reduce transportation cost and get advantage of cultural proximity. Therefore, Toyota uses decentralized strategy successfully as establishing development units around the world to respond for specific region requirements. Decentralized development means having access to local information networks, which Toyota reaches well but Volkswagen does not. Since Volkswagen development units are limited to a certain area, it is not capable of producing region-specific vehicles. Decentralized development sites and local developers more fitting with culture and consider the living condition in that region, overall they increase company's responsiveness to a given market, which leads to increase sales. As a result, they are more sensitive to local customer expectations and allow customized models that meet local needs. However, since Volkswagen corporate culture is still strongly tied to the

home country, it applies German standards to its vehicles. This is another issue along with a lack of local production sites, why Volkswagen has not been more successful in the US[15].

To conclude with this report summary, companies will not be successful globally unless they adapt their products to the needs of the respective markets. Volkswagen cars often are too sophisticated and expensive for emerging markets. For instance, Volkswagen designed a car for Indian market, which have twelve-year anti-corrosion finish, while this is not such feature that Indian customers concern, and features like this make Volkswagen cars unnecessarily expensive. Moreover, German attitude insist on using expensive technology, which is not preferable for emerging markets. Toyota strategy, adequate design of cars with reasonable sales strategy to the region. With the standardization of its vehicles and adaptation to markets, company able to produce large numbers of basic modules with low unit costs while considering the local tastes [15]. Like Toyota strategy, 'Global best, local best' is the main motto for distributed manufacturing and Microfactory approach developed in this study as well. Global best refers to building cars with common standards worldwide with highest level of quality and performance. Local best refers to reflecting the needs and values of customers in different regions. In addition, 'glocalization' with the definition of adaptation worldwide to local conditions is the term to represent this strategy in literature[15–17].

In addition to that the distributed manufacturing in literature is usually concerned with potential sustainability improvements, distributed manufacturing is considered as a decentralization of centralized production. Within such conceptualizations, centralized production system can involve the full scope of operations, including R&D, procurement, manufacturing and sales, being carried out at one place in one country. By contrast, decentralization involves there being no constant company transportation link between home and host countries; with every globally distributed production location being able to deal with all of production steps from procurement to sales by itself. In a combined production strategy, operations can be done in both a company's home country and in host countries where there may be raw materials, production units and/or sales centers. This strategy can involve complex transportation networks, which span several continents [18, 19]

The term, Distributed Manufacturing (DM) has been used to described where manufacturing locations of one enterprise are geographically dispersed [16]. The term, Distributed Manufacturing Systems (DMS) has been used to describe the combination of multiple manufacturing units intended to have the features of autonomy, flexibility, agility and decentralization[20]. Distributed manufacturing and distributed production have been used interchangeably when describing processes intended to provide agile customization [21].

The common explanation whatever it is called distributed manufacturing, distributed systems or distributed production, all differentiates itself from mass production with regards to production locations, facility and/or batch sizes, consumer satisfaction, and/or the organization of the supply chain network[21]. Decentralized production networks with distributed production units provides individualized products to local customers with the consideration of cost, time, CO2 emissions, energy consumption and quality[16]

The one of the most seen application method of distributed manufacturing system in literature is mini-factory network design which doesn't clarify enough how much flexibility it has. The important feature that is emphasized more; they are geographically distributed production facilities, able to adapt quickly changes in product specifications according to local needs[22–26].

These high levels of automation are mentioned the distributed manufacturing being dependent upon, and synonymous with, digitalization enabled by Cloud Computing and computer-numerically controlled manufacturing (CNC) equipment [27]. Thus, decentralized manufacturing is highly connected with recent production themes such as Industry 4.0 and Smart Manufacturing [27, 28].

In literature, being 'local' is referred to main sustainability benefit of distributed manufacturing due to reducing environmental impact because of long distance transportation [21]. The ability of direct response to customer wishes, market demands and international situations are defined as 'real-time economy'[29]. The organizational form of this 'real-time enterprise' has ability to allow quick changes as customer order activated the most part of value chain and it reduce lead time. Therefore, distributed mini-factory networks are new organizational approach an mini-factory network is ideal model for real-time enterprise [23]. A mini-factory is where customer needs occur, real time management

takes place in there. The independent mini-factories seems to be increase instead of establishing new factories overseas in the future.

Distributed manufacturing system is mostly used in literature with mini-factory network design, which does not clarify enough how much flexibility it has. The important feature, which is emphasized more, is modularity but just include product variety. Location fix, but geographically distributed production facilities, able to adapt quickly changes in product specifications according to local needs.

When the region infrastructure is taken into consideration, to be able to get benefits from emerging market with low cost and environmentally friendly way is building moveable small factories. The lack of physical infrastructure is not a problem because factories are not fixed, they are able to move easily to place where the demand is, where the supplier is, where the production is better...etc. Transportation costs is minimized by both material and product sides since these factories are like assembly plant, it means they buy more than make so no such material transportation cost include[10].

2.2 Microfactory Definitions

There is only five thesis studies when it is searched for 'microfactory' in YÖK Thesis Center, and when we analyze them it can be clearly understand they are referring the desktop manufacturing and micro scale assemblies while microfactory concept developed in this study is unique and completely different in the literature [30, 31]. Therefore, this study contribute the literature with a novel production model and its further discussions. The vagueness in defining distributed manufacturing is discussed previously [10]. Similarly, the variety of definition in the term 'microfactory' exists in literature. There are terms such as modular manufacturing system, flexible manufacturing, smart factories, and the factory for futures, mini-factories, and eco-factories related to distributed manufacturing.

'Mini-Factory' is a small scale production unit able to make highly customized products with respect to local tastes with low cost and short delivery time [22]. Even if it is designed as scalable and modular [23] this flexibility allows to quick changes in manufacturing according to locally customized based goods[24]. It is claimed that this feature provides easy adaptable production system as designed as a few-small- fixed buildings in

different locations [25]. Each unit is able to operate its functions under one roof and they are connected to each other in company's global network system. They must be located close to customer to be able to respond customers' specifications well and produce customized products and should provide customer service include repair and maintenance in addition to sales and production activities[26]. In extended literature, Mini factory is mentioned as a marketable, miniaturized highly flexible robotized micro-assembly system [32, 33]; as well as high precision, self-calibrating, agent based, distributed assembly system [34]. Furthermore, a specific classification for microfactory systems was offered as a manufacturing method by desktop factories and fabrication by small robots, but all classifications consider small production systems to produce small products[35]. 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 is defined by Tampere University of Technology (TUT) as a modular construction kit type concept with easy and rapid re-configurability for the different manufacturing process of handheld size or smaller products which the dimension of one module is 300x200x220 mm [36].

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 [37]. The maker movement platforms also use the Microfactory concept as the place where the product is engineered for innovation and collaboration [38]. With access to 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 and rapid prototyping tools help products to quick move from the concept to creation to showroom floor[38].

As a result of the literature reviews, Microfactory can be fit under unlit/industrial distributed manufacturing in the taxonomy given in Chapter2 since they are geographically distributed, scalable, modular, highly automated production units. When considering its Industry 4.0 infrastructure such as IoT, 3D manufacturing etc, microfactories can also related to 3rd Wave DIY [10].

2.2.1 Definition of Microfactory Specific to This Study

As previously mentioned above, much of the current literature on Microfactory pays particular attention to describe small desktop manufacturing of systems. Throughout this paper, the term microfactory is defined differently. This approach eliminates the major cost items in production line such as press and dies in car manufacturing, reducing a plant investment cost by 90 percent. The key features of a microfactory are flexible production and economically scalable manufacturing plants. The aim of this study is to introduce a 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. The illustration of energy independent Microfactory building is given in Figure 2.3.

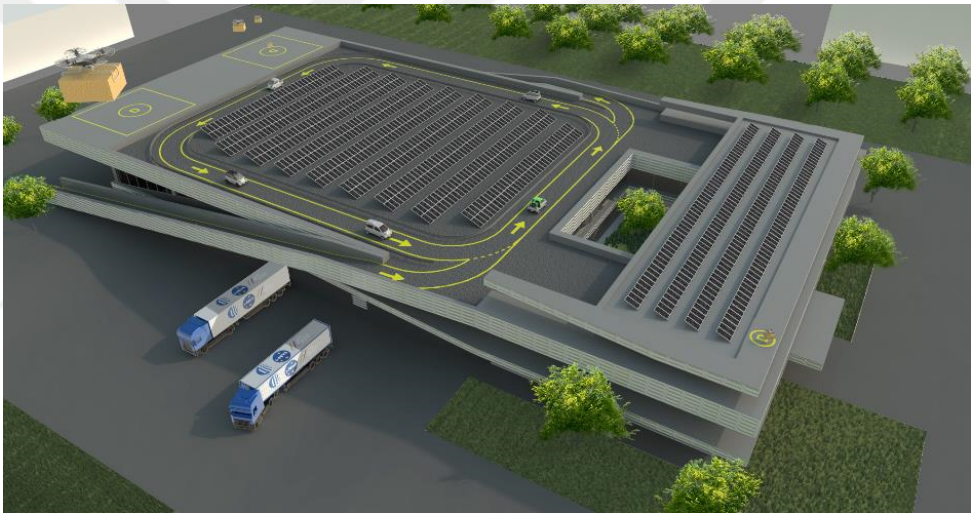

FIGURE 2.3: The Energy Independent Microfactory Building in which the solar panels produce the necessary energy to run the factory [39]

The Figure 2.4 shows some inside view from microfactory. The factory layout which is described in detail, is designed to operate all the production activities in same plant.

2.3 Opportunities in EV/Car Industry

There is a de facto monopoly of the conventional ICE motorization, which will be described in in more detail Chapter3, it is difficult to enter into the car-maker industry. Electromobility represents an opportunity for emerging markets to produce their own cars with national technologies. Large potential markets for microfactories are in Turkey,

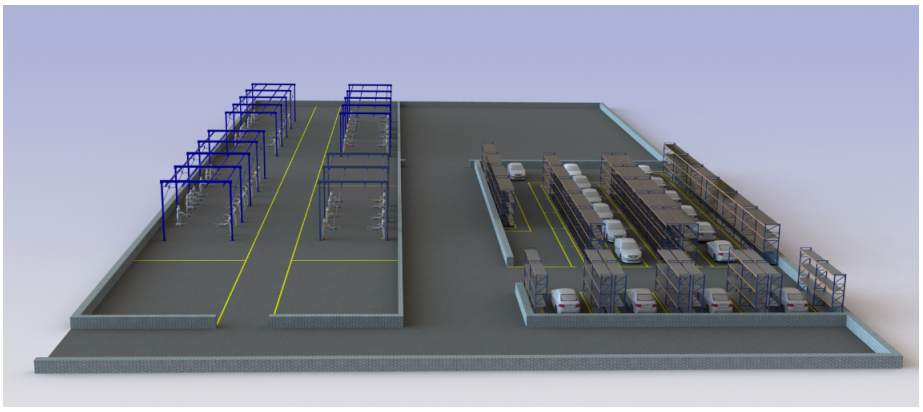

FIGURE 2.4: Assembly area of Microfactory

Russia, Poland and all other regions in the world having large manufacturing capability in automotive and strong motivations to establish their own national brands. There are also other potential markets for microfactories among mobility as a service providers "MaaS" (ride-hailing and ride-sharing companies, see difference of two terms in [40]) 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 advance 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 such as COMAU, the CLN group or others would potentially provide strong market entry for microfactory concept in car production. The future technologies in automotive are:

- Electric Motors
- Tubular Chassis
- 3D Printing

Chapter 3

The Comparison of Conventional and Microfactory Concepts for Car Manufacturing

3.1 Conventional Car Manufacturing

The current car manufacturing has been described in many reports and online media (e.g., car factory assembly line). 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 steel or aluminum), followed by robotized welding assembly. 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 Industry 4.0 technologies, therefore most of the operations are made automatically. The human activity consists of setting up the moulds and the parameters of the presses. For instance, Nissan presented 5200 tones servo transfer press, which require extra-large press area to use in Sunderland plant, is showed in Figure 3.1 [41].

A vision of the robotized welding islands to assemble the stamped metal sheets is shown in Figure 3.2 (left) and the final lower part of the chassis is shown in Figure 3.2 (right)

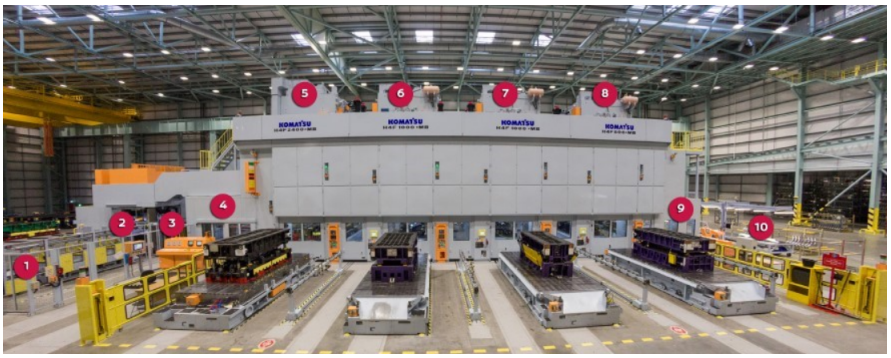

FIGURE 3.1: A giant Servo transfer press for molding operations in Nissan Sunderland plant [41]

[42] . The number of moulds and complexity of assembly require huge investments, 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.

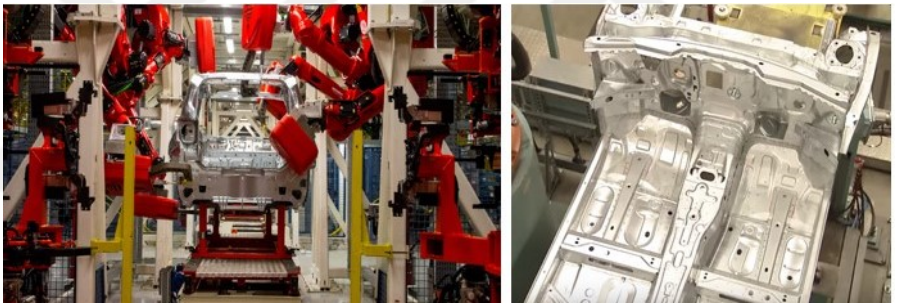

FIGURE 3.2: Assembly line in car manufacturing plant (left) and the lower part of chassis (right) illustrate the complexity of operations in conventional car factories [42]

Similarly, to the chassis, the manufacturing of innovative ICE requires huge investments and knowledge representing another big obstacle to anybody 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 [43]. 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 someone is a new comer to the existing market. This automatically makes the process more sustainable in terms of the cost end 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. In this perspective, the microfactory suggests a breakthrough-manufacturing model to produce new generation EVs.

3.2 Microfactory Concept for Car Manufacturing

The conventional automotive industry has three main de facto monopoly:

1. Internal Combustion Engine (ICE): includes full of complexity
2. Chassis: High initial investment cost
3. Government funding

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. Table 3.1 summarizes the main disadvantages of conventional manufacturing and solutions offered by microfactory concept.

The electric powertrain challenges the first monopoly. Focusing the attention on the powertrain, the question for a new manufacturer is to secure the supply chain. The

TABLE 3.1: The monopolies of conventional car manufacturing and microfactory option

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

important point here is to define the right designs and selecting the right suppliers to be independent from critical components/systems. The conventional automotive world relies on alternative suppliers even for the simplest components. To emphasize the concept, within the automotive world, it is usual to state that a supply chain is properly secured when each screw could be purchased from three different suppliers. In few words, freedom of operation is one of the fundamentals of the automotive world. For instance, consider the power electronics: there are only two large semiconductor companies in Europe 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 bare steel with aluminum, sometimes reducing the total weight up to 20-30% [44, 45]. With the advent of Super High Strength Steel (SHSS), it has been demonstrated

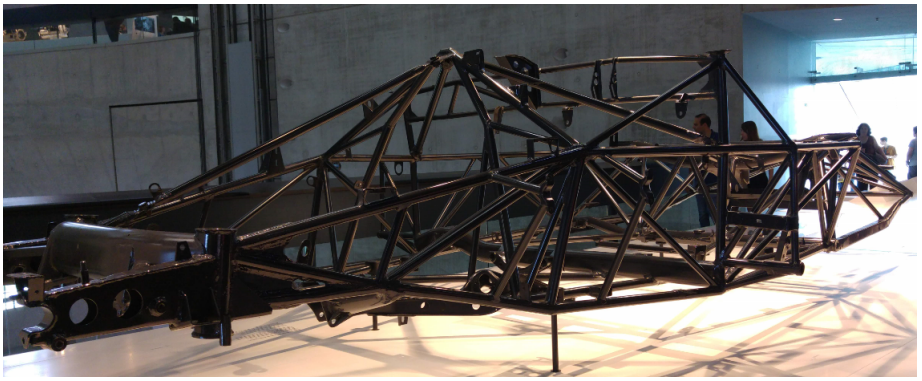

FIGURE 3.3: The initial tubular chassis example from Mercedes, Three box design. (Photo: Mercedes-Benz Museum, Stuttgart, 2018)

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. Initially tubular frame chassis was used for race cars, for instance Mercedes Benz use since 1950s, three box design (sedan), engine is under the hood and surrounding is the first box, passenger seating area is second and cargo area is the third box. (See Figure3.3) 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 [46]. 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.

A remarkable novelty has been introduced in this study, a tubular-based chassis design to facilitate the coupling of body panels (Figure 3.4). The developed tubular chassis using a blend of SHSS with defined characteristics on strength, thickness, and sizes is manufactured with no moulds and very simplified templates. The result is that very

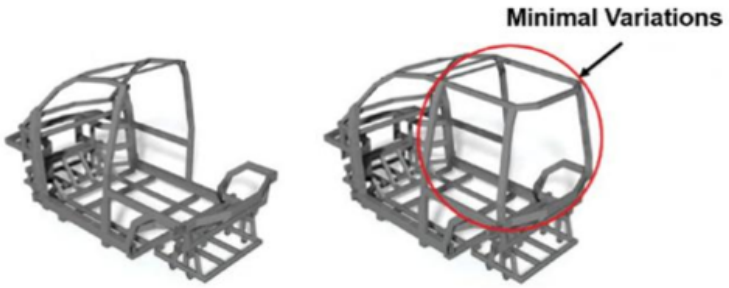

FIGURE 3.4: The tubular chassis structure for Microfactory based EV [39]

low investment is needed to meet the most severe EuroNCAP crash tests (full frontal, off-axis and side crash tests).

The proposed design is also characterized by allowing the manufacturing of considerably different architectures with minimal changes in the production line. Figure 3.5 shows different architectures resulting from 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. 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.

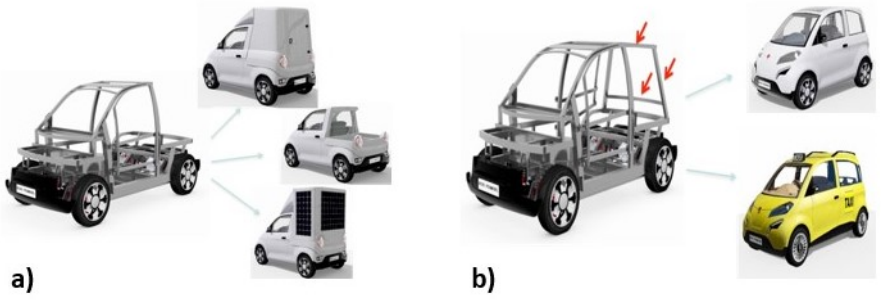

FIGURE 3.5: The same chassis for pickup, food delivery and restaurant cars (a); same chassis for passenger and taxi cars (b) [39]

Referring the literature review in Chapter 2, although the main principles are similar, the term of microfactory has to be related to a specific topic. 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 battery pack, painting, 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. When the demand exceeds what is possible in the third shift, another microfactory has to be established thus introducing parallel manufacturing concepts.

The microfactory leads to a new form of distributed parallel manufacturing that replaces the concept of the Giga factory. Like parallel computing replaces large mainframes and distributed renewable energy sources replace large power plants, the microfactory represents a low investment and flexible alternative to the usual automotive Giga factory concepts.

3.3 The Microfactory Concept Description: Flexible Manufacturing of EVs

Because of the approach adopted in this model, 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.

3.3.1 Microfactory Layout

The layout of the microfactory for EV production is shown in Figure 3.6. 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.

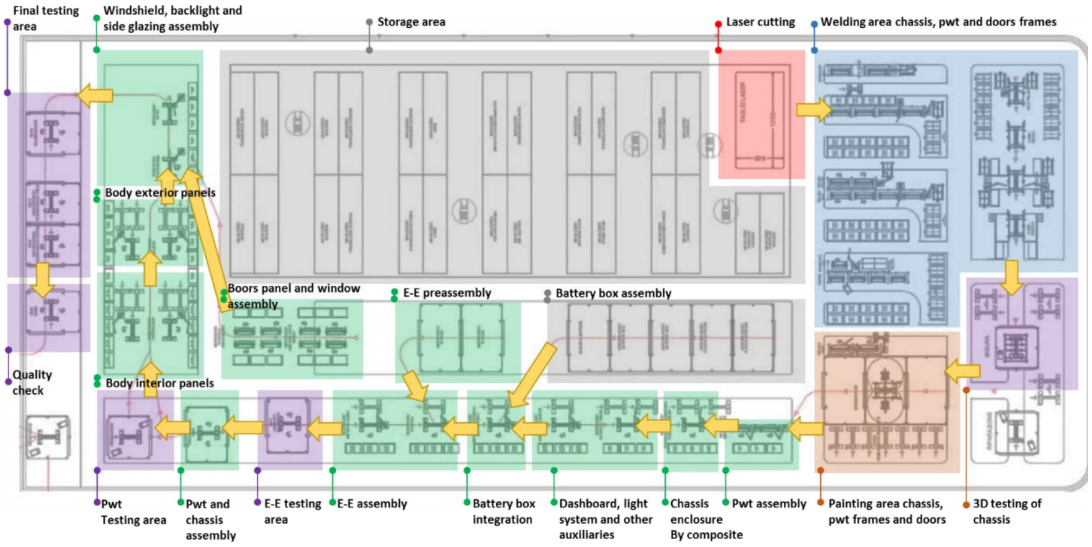

FIGURE 3.6: The Layout of a Microfactory for EV where the operation starts from laser-cutting stations (in red) and ends with final quality checks (in violet)

Laser cutting, the red zone in Figure 3.7, 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 3.6

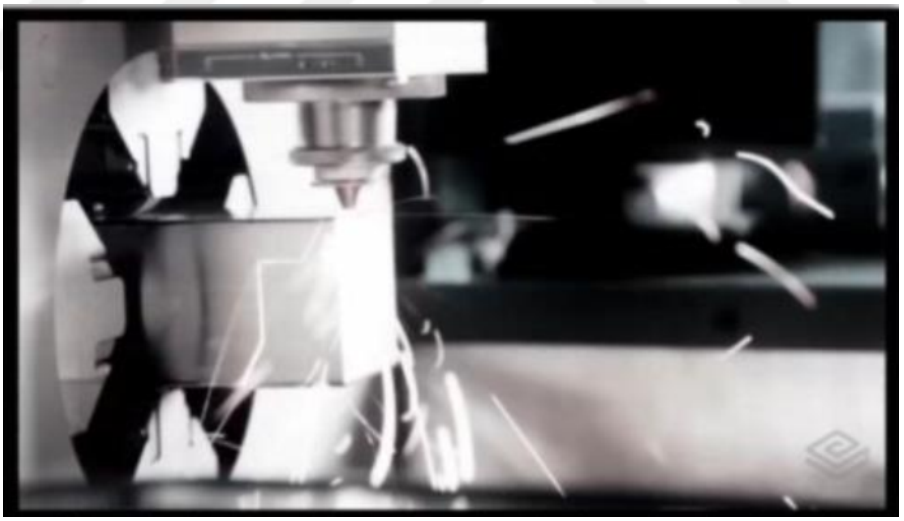

FIGURE 3.7: CNC automated Laser cutting of chassis tubulars

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 doorframes 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 lover and the upper sub assembly 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 3.6. 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 3.6, 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 tests 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.

The Figure 3.8 also represents an example of initial design for microfactory layout, the assembly cell can be shown in the front.

Since the high automation infrastructure is needed for unlit distributed productions, 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 battery assembly, e-motor assembly and body assembly, presented in Figure4. 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

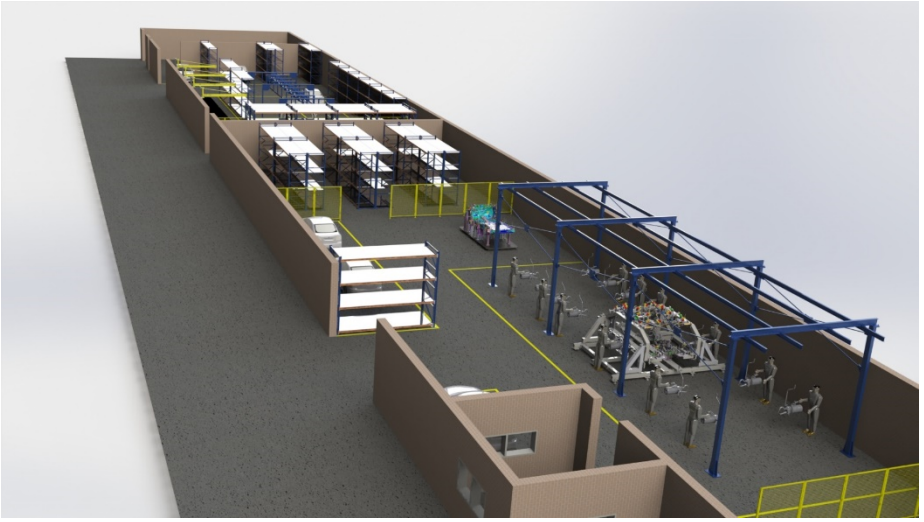

FIGURE 3.8: The production Layout inside the Microfactory

chassis eliminates moulds in production line with appropriately designed in 3D printed parts (Figure 3.9)

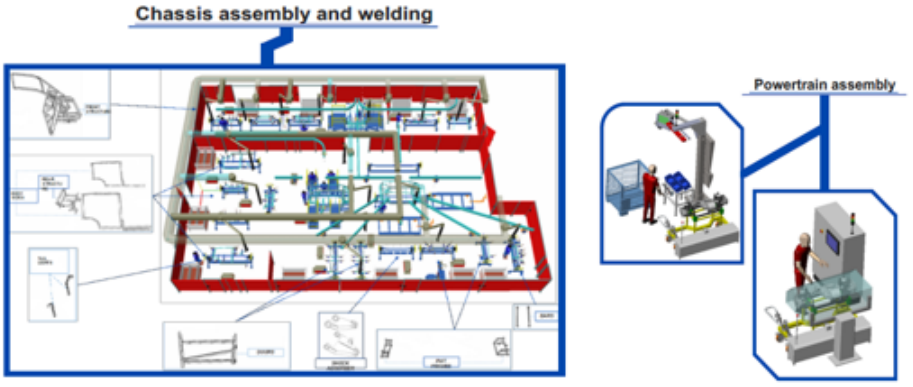

FIGURE 3.9: Industry 4.0 infrastructure of microfactory provided by Comau

3.3.2 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).

3.3.3 Human Interfaces

The possible scenarios for human integration in the flexible production systems are Human-in-the-Mesh and Human-in-the-Loop (Table3.2)

TABLE 3.2: 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 (role, location)	Context-aware mobile devices (role, location)
Intuitive representation of alternatives and trade-offs	Support visual inspection with sensors
Decision support enhanced by experts decision-making patterns	Support testing (geometrical, power train, fatigue, etc.)
	Virtual presence (for consulting expert colleagues: sharing view, screen, info, voice connection or chat)
	Multimodal interaction (voice, image, gesture recognition, sounds, lights, etc.) to alert and support field-work
	Suitable/wearable device to support field-work
	Asset tracking (tools and spare parts)
	Localisation and turn-by-turn navigation to retrieve machines, tools, spare parts

The factory system architecture is shown in Figure 3.10. 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.

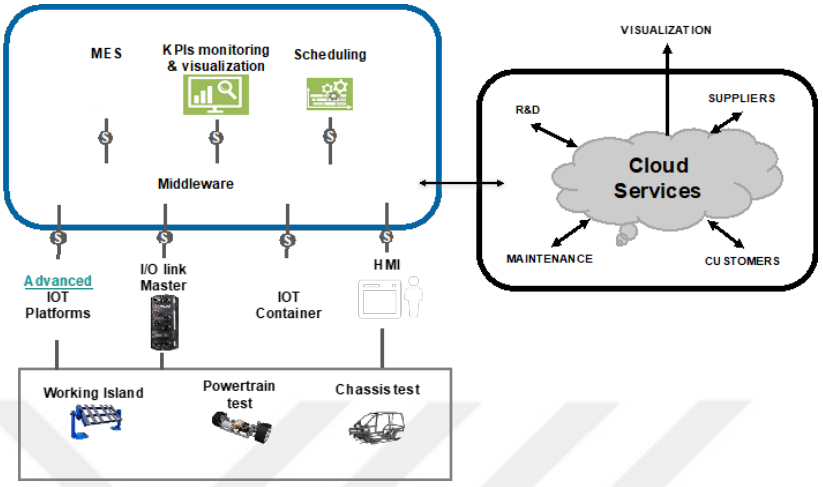

FIGURE 3.10: The factory system architecture

IO-Link is a powerful standard, an increasingly deployed point-to-point serial communication protocol used to communicate with sensors and/or actuators. Extending the globally recognized PLC standard IEC 61131, it allows three types of data to be exchanged; 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 3.11.

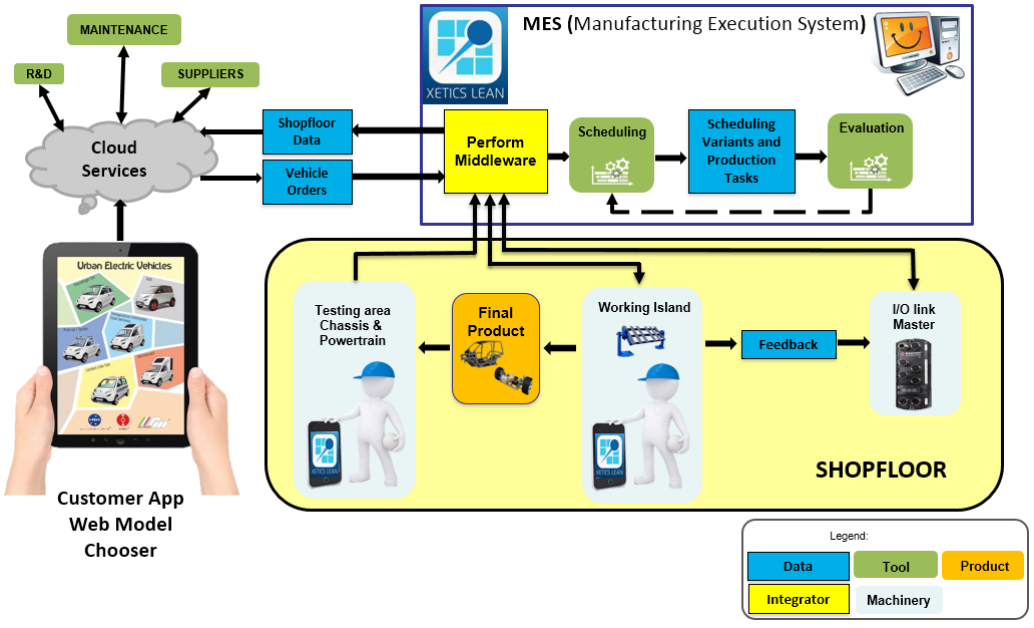

FIGURE 3.11: Workflow

Chapter 4

The Proposed Supply Chain Model

4.1 Sustainability

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[24]. Building a microfactory concept satisfies those dimensions in different degrees. Table 4.1 summarizes these four dimensions. Building a microfactory for EV production factories satisfy those dimensions in different degrees. economic point of view, distributed manufacturing, with the proximity to customer provides more customer satisfaction, flexibility for customized products leads more product value. Company may add special feature according to region specifics or subtract unnecessary ones for those customers. Proximity to demand provides to decrease delivery time and cost of carrying products at certain level but material supply cost increase in this case. Distributed manufacturing, producing in local have huge reduction in transportation volume, but it is valuable when you locate somewhere close to customer and supplier. Highest impact of distributed localized manufacturing can be seen in social dimensions. Establishing microfactories to emerging regions with less initial cost according to Giga factories, create jobs for local people and decrease unemployment rate while prevent the migration also. Cities, which have production facilities, develops with attaching related institutes, subindustries etc. Universities will collaborate and quality of education make sense because now demand exist and they feed each other. Distributed manufacturing provide also distribution of these opportunities and can handle of restricted infrastructure. Mostly local people,

who are not high qualified, take advantage of them. Welfare increase homogeneously, and it makes sustainable peace and tranquility in long term. For Turkey like countries perspective, as political dimension, government's ongoing project on manufacturing its own domestic car will be achieved its aims and politically financed projects increase for sustainable manufacturing. Local manufacturing enterprise also increased because government has encouragement also. New regulations can be arranged to reduce CO2 emissions

1. Economic sustainability is fulfilled by cost comparison such as investment cost, operation cost, labor cost and life cycle cost. The proximity to customer provides more customer satisfaction with more flexibility for customized products, which lead 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.

2. Ecologic sustainability is satisfied by environmental sustainability indicators such as CO2 emissions, air pollution, energy consumption and land use from manufacturing and driving of vehicles. EVs reduce transportation emissions by its design, while gasoline cars are heavily dependent on limited oil reserves. Microfactory buildings can be designed to be energy independent by the use of solar panels integrated with batteries for continuous clean power.

3. Social sustainability is fulfilled with the truth that work steps by human operators are simpler, even if microfactories are highly integrated with digitalization. The local manufacturing creates new job opportunities where high engineering skills are not required. Although conventional automotive industry has higher social benefits in terms of employment, tax and compensation, microfactories can compete with it with employment impact in large scale if the government incentives and well-designed supply chain are created. Besides the employment, e mobility favors the human health impact in high degree compared to ICE vehicles [47].

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 EV powered by renewable energy sources[48]. Therefore,

most countries are planning to become fossil fuel-free on the road by 2050[49]. The French government propose up to 2,500 euros incentive to switch to a less polluting vehicle [50]. Costa Rica plans to become fully decarbonized by 2050 and zero emission public transportation by 2035 with removing gasoline and diesel from road [51]. The Asian countries are aiming to completely phase out petrol and diesel cars in favor of EVs [52].

In the light of this roadmap, although BEVs are niche products that change overall established automotive industry, it faces multi-level obstacles against such transition. These monopolies are already mentioned in this paper as it is known that high technology and knowledge required to make ICE motor, BIW and a well-defined supply chain are needed. These barriers create price, range, infrastructure and technological uncertainty barriers to a faster adoption of these vehicles[53]. In addition, these factors lead to a situation where BEV market entrance remains far below the level required for mass-market transition. The multidimensional governance approach should be taken for BEV to 'cross the chasm' [54, 55]. The effective policy mechanism is investigated for Nordic region[53], they 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 with a long history encouraging BEV adoption such as exemption from roadway tolls, access to charging infrastructure, tax incentives, and right to use of bus designated lanes [56]

The importance of industrial policies is analyzed for the case of Turkey and South Korea [57] . 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 concept is feasible to satisfy institutional sustainability dimension.

TABLE 4.1: 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:** High investment cost and high technology and knowledge required in manufacturing process. The market is captured by existing OEMs. **Social:** Employee profile includes mostly high-skilled people.
Microfactory key elements: Powertrain Tubular chassis	**Ecological:** While EVs reduce emissions on the road, minimizing manufacturing process 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, it creates local jobs. And major favor in human health. **Economic:** Traditional cost barriers broken down. Cooperative R&D&I decrease engineering cost. **Institutional:** Traditional access barriers can be broken down with government incentives.	**Economic:** not competitive with global manufacturer. Difficult to reach Tier 1 suppliers as a new comer. A specific supply-chain model should be applied.

4.1.1 Sustainability and Future Car Industry

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. It is presented in many reports that the electromobility leads to a radical reduction of green gas emissions and use of oil[1, 58–61]. For instance, a typical mid-size electric vehicle (EV) can generate up to 67% lower GHG emissions

than a gasoline ICE car on a well-to-wheel basis [62]. Electric vehicles 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 material. Electric vehicles are not a panacea, but they offer a way to significantly reduce GHG emissions through more renewable energy distribution and decarbonization of the electricity grid [63].

On a well-to-wheel basis, GHG projected emissions from EVs will continue 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, the degree ultimately depends on the power mix: CO2 emissions savings are significantly higher for electric cars when the power generation is dominated by renewable sources such as wind, water, photovoltaic, geothermal energy, biomass or animal waste. In contrast, in countries where the power generation mix is dominated by coal, hybrid vehicles exhibit lower emissions than EVs [1]. 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 4.2.

TABLE 4.2: Energy cuts comparison between conventional gasoline car and mid size BEV [59, 64]

Conventional Mid size ICE Car		**Total CO2eq emissions**
Well to Tank	**Tank to Wheels**	
35gCO2/km	140gCO2/km	175gCO2/km
Mid size BEV (150Wh/km)		**Total CO2eq emissions**
*electricity produced by a modern plant of coal		127gCO2/km
*electricity mix 23%nuclear, 42%renewable,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 road transport. 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 5.3. EVs means a potential for primary energy savings by 30-40% and GHG reduction up to 67%. On the other hand, in the last two decades, the improvement in powertrain efficiency of a conventional ICE car (including all transmission) is just %5, as seen in the Table 4.3 .

TABLE 4.3: The primary energy consumption of EV and comparison to conventional powertrain[65]

Year	**Power Plant Effic.**	**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						120	600
ICE 2017	Powertrain efficiency of a conventional ICE car 0.25						120	480

Depending on battery technology, manufacturing of EVs is expected to become a cost-competitive alternative to ICE vehicles in the mid-2020s [60]. Proposed microfactory model to produce EV economically feasible from investment to operation. For instance, in the current automotive industry, about 6000 components used to produce a conventional ICE car. On the other hand, microfactory provides an alternative EV platform that simplify assembly operations and could reduce unit cost of vehicle up to ten times. In general, prototypes produced with pre-production by conventional technologies will cost above 100 M€. (Establishing a conventional car factory is approximately 500 million

USD) Within the microfactory, the total cost of first prototype in early stage would be proximately 10 M€. Predicted key cost items are shown in Table 4.4 and the total production cost of one unit is estimated to be 10800€

TABLE 4.4: Cost estimation to produce an EV at the microfactory

Key components	**Price (in thousand)**
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

4.2 Sharing Model

A microfactory can be made profitable within the first year of operation 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. Although a product is conceived and assembled inside the factory, there is still a need of a well-defined supply chain for the motor/inverter, tubular SHSS, electronic board lights, seats, battery cells, etc.

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. 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 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 engineering cost while increasing 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 is making 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.

4.3 Blockchain Technology for Supply Chain Management of Microfactory Network

Since smart factories enable rapid retooling, small-scale manufacturing facilities may actually have a competitive advantage to produce customized products for specific local needs, at a local scale. Microfactory concept in this paper is presented as a novel production facility to manufacture new generation electric vehicles.

Local Motors established automobile-building micro-factories across Phoenix, Las Vegas, and Knoxville, and host an open library of vehicle designs to include and empower communities of global designers, engineers, manufacturers and automotive enthusiasts. It can be claimed that, with the advanced technology, there is a potential for a decentralized production to democratize the manufacturing function, as the Internet makes the information accessible for everyone, designing and manufacturing would be more accessible to everybody within distributed manufacturing. However, weak supply chain infrastructure can lead to high distribution costs. For this reason, supply chain security is critical for microfactory networks. The well-defined supply chain for components such as the motor/inverter, tubular SHSS, electronic board, lights, seats, battery cells, etc. is required. It can be improved by integrating blockchain technology to the supply chain for future studies.

Blockchain related supply chain use cases are also considerable for automotive industry. Figure 4.1 is summarize the potential application areas for automotive industry to use blockchain technology.

Each microfactory/country has the capability to create its own brand with customization according to demand of its local market. The proposed network model for microfactories is the collaboration to make their local brand stronger and compatible in already captured automotive industry. Therefore, a globally distributed network will be established with the replication of microfactories. To succeed in this highly distributed network, central authority is required. However it is not defined in sharing economy concept developed for microfactories. The distribution of data into the network securely without intermediaries is a challenge of this model. However, this can be overcome by implementing blockchain technology, which allows transacting peer-to-peer and trusts each other by using collaboration and cryptography without a third party [67]. It means all

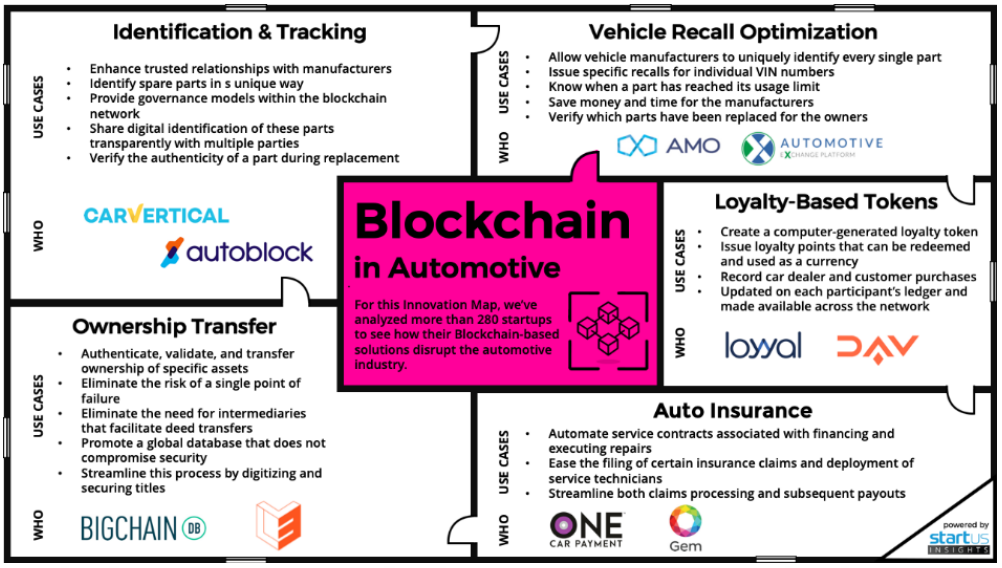

FIGURE 4.1: The areas within the automotive sector improved by blockchain[66]

transactions will perform between related microfactories and engaged suppliers, a central authority to control and manage the system is not needed. The data of all microfactories distributed across a global ledger, using the highest level of cryptography. To hack a blockchain network, someone needs to reach all computers in that network which is almost impossible, thus blockchain offers a more secure model, which can be adaptable to the microfactory network. Consequently, this microfactory network consists of a smart contract between parties that allow us programmatically to define the rules and steps that should be performed any time a certain type of event is recorded in our blockchain or in our magic notebook.

Blockchain is a simple way of passing information in a fully automated and safe manner without need for intermediaries since 'central authority' does not exist. Besides it provides transparency, speed, accessibility and coherence so that the blockchain logic fits the business model of microfactory networks.

Chapter 5

Discussion and Conclusion

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 would potentially provide strong market entry for microfactory concept in car production.

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 central authority is required which is not desirable in this network as it is explained by sharing economy.

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 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, energy waste and 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.

This study set out to evaluate a novel design for manufacturing electric vehicles through microfactories, which provide flexible and customized production of EVs minimizing both ecological footprint and the total investment. The conventional car manufacturing is described to show its current system in terms of high investment and the level of complexity. 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. Therefore, large car makers have a monopoly as they have the knowledge for decades; they have top tier captive supply chain, government support and the capital. As a result, conventional techniques require to large-scale production to reach desired ROI. We described Microfactories to break this closed loop monopoly between OEMs-TIERs-governments.

Since electric powertrain challenges 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 supplier monopoly and to attract government subsidies. The proposed sharing creates a community of microfactories of globally distributed network.

The microfactory concept analyzed in this thesis makes several noteworthy contributions to sustainable production in case of manufacturing new generation electric vehicles.

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