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Supply Chain Network for Battery Electric Vehicles and Cost Model for Battery Packs

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Supervisors

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Affidavit

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Acknowledgement

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Abstract

Today, the automotive industry is looking for diversified powertrain portfolios. The shift towards the electric vehicles is looking apparent. Due to the increasing CO_2 emissions, and reliability on the fossil fuels the automotive industry is looking for alternative solutions. With respect to the electric cars, the supply chain differs to a greater extent compared to the Internal combustion engine car manufacturing supply chain. This has resulted a change in many processes and sub-processes. One of the major changes the industry has faced is in the area of supply chain management. The thesis aims at identifying the changes in the supply chain for electric vehicle manufacturing.

The Master thesis is conducted in collaboration with AVL List GmbH, Graz. The results of the thesis provide an insight into the supply chain networks and strategies for the electric vehicle manufacturing. It helps to identify the potential parts of the electric powertrain, which can be strategically outsourced to the best-cost providers. The thesis is divided into two parts, which comprises the theoretical framework, and an empirical part of the topic.

The theoretical framework discusses the underlying concepts of the electric vehicle and its manufacturing process. It also discusses the potential parts of the electric vehicle, concerning their value for the overall value chain. One of the concepts of best-cost country sourcing is discussed in detail in this section. Best-cost country approach is considered for the sourcing of potential parts for the electric powertrain, which helps to achieve cost savings in manufacturing of the battery packs. The automotive supply chain concepts are also a part of the literature review in the thesis.

The empirical part consists of two sections. In the first section, the implications on the supply chain for electric vehicle manufacturing are discussed. This also leads to the various supplier networks and different strategies implemented in the electric vehicle industry. The later part consists of a cost model for battery pack manufacturing in the best-cost countries. The cost model helps to evaluate the total cost breakdowns in the battery pack manufacturing and shows the cost potentials of best-cost country sourcing.

Zussamenfassung

Die Automobil Industrie sucht derzeit nach diversifizierten Triebwerken. Die Umstellung hin zu elektrischen Fahrzeugen ist offensichtlich. Passend zu den steigenden CO2 Emissionen und zu der Beständigkeit der fossilen Brennstoffen sucht die Automobil Industrie nach alternativen Lösungen. Die Prozesskette eines elektrischen Autos unterscheidet sich maßgeblich, von den Fahrzeugen mit einem internen Verbrennungsmotor. Daher resultiert eine Veränderung in vielen Prozessen und Sub-Prozessen. Eine der Hauptveränderungen befindet sich im Bereich des Lieferantenmanagements. Das Hauptthema dieser Masterarbeit ist es die Veränderungen der Versorgungsketten von elektrischen Fahrzeugen zu identifizieren und zu fabrizieren.

Die Masterarbeit wurde unter Zusammenarbeit im AVL List GmbH in Graz, ausgeführt. Die Resultate der Arbeit geben einen Einblick in die Netzwerke einer Versorgungskette und Strategien für die Anfertigung von elektrischen Fahrzeugen. Die Ergebnisse helfen den potenziellen Teil eines elektrischen Triebwerkes zu identifizieren, welches strategisch zu den günstigsten Dienstleistenden ausgelagert werden kann. Diese Arbeit ist in zwei Teile gegliedert, diese umfassen den theoretischen Rahmen und den empirischen Teil dieses Themas.

Der theoretische Rahmen diskutiert die zugrundeliegenden Konzepte eines elektrischen Fahrzeuges und dessen Herstellung. Es diskutiert auch den potenziellen Teil eines elektrischen Fahrzeuges, hinsichtlich des Wertes der gesamten Ketten. Eines der Konzepte für die Beschaffung in den günstigen Ländern wird darin näher beschrieben. Günstige Länder zum Beschaffung des Potenzials heranzuziehen ist wohlüberüberlegt bei den Triebwerken der elektrischen Fahrzeugen, diese helfen kostengünstig die Batterie Packs herzustellen. Die Konzepte der Automobil Versorgungsketten sind ebenfalls ein Thema in dieser Arbeit.

Der empirische Teil besteht aus zwei Abschnitten. Im Ersten Teil, wird auf die Durchführung bei der Herstellung einer Versorgungskette für elektrische Fahrzeuge eingegangen. Das führt zu den vielfältigen unterstützenden Netzwerken und zu den unterschiedlichen Strategien die in der elektrischen Fahrzeug Industrie umgesetzt werden. Der letzte Teil beschäftigt sich mit den Kostenmodel der Batterien Pack Herstellung in kostengünstigen Ländern. Das Kostenmodel hilft den gesamten Kosten

Aufschlüsselung der Batterien Packs bei der Herstellung zu evaluieren und zeigt das Kostenpotenzial der Finanzierung in den kostengünstigsten Ländern.

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1 Introduction

The Automotive industry has been changing tremendously from the past years, mainly due to increasing emission regulations, growing concern over global warming, reliability on existing fuels and customer demands. In addition, the continuous pressure on reducing prices and an accelerating competition already affect the industry hit by such challenges.[1] The new competitors are aggressively entering the markets with an aim to capture their global share. Furthermore, the alarming emission levels are pushing the automakers to alter the entire structure of the industry. Therefore, the Original equipment manufacturers are looking for an alternative Powertrain technology. As a result, they are putting in a huge amount of investments in the development of electric cars.[2] In support for this, the governments are introducing various incentives for the use and purchase of the electric cars. However, due to the high costs of the battery and small driving ranges, the electric cars are put in the niche category.[3] In order to resolve these issues, the automobile companies are implementing various new techniques and technologies in the field of electric car manufacturing.

EXTERNAL	CUSTOMER	COMPETITION	INDUSTRY
Legislation (Emission, Safety)	Stagnating demand	New Entrants	Complex Alliances
Raw materials, Energy costs	Price pressure	Moving targets	Global overcapacities
Customs, Exchange rates	Segmentation and Polarization	Entry in every segment	Consolidating Ecosystem

Table 1.1 Global trends and challenges in the automotive industry[4]

The table illustrates the global trends and challenges in the automotive industry with respect to the general aspects. These trends are influencing the shift towards the electric cars, which will drastically change the other related industries as well. Nonetheless, this paradigm shift is in the making and would very well revolutionize the

[1] Gao, P. Wang, A. & Wu, A. (2008)

[2] Klug, F. (2013), p. 1

[3] Klug, F. (2013), p. 8

[4] Schwarz, M. (2008)

automotive industry. The shift towards e-mobility will completely alter the traditional parts and processes, thereby transforming the supply chain of the current industry.[5] Thus, this report will help to understand how the electric car manufacturing transforms the automotive supply chain.

1.1 Company overview

The master thesis is conducted at AVL List GmbH, Graz. The company deals with the development of the powertrain systems with internal combustion engines and test systems.[6] It is an automotive supplier for the development of powertrain systems for mobility. The company works in collaboration with the leading automotive OEMs around the world. It deals with the development of simulation platforms and a set of simulation tools for component prototyping. AVL List GmbH also develops new solutions for powertrain technologies in order to find solutions for reduction of CO_2 levels.

The master thesis consists of supporting a supply chain strategy for electric vehicle manufacturing. AVL List GmbH is actively participating in the development of electric powertrain, and battery technologies to provide their customers a leading edge in the technology. Currently, e-mobility is a highly demanding technology and the OEMs need expert solutions on this topic. With the help of this master thesis, AVL List GmbH tries to find the exact implications on the supply chain management area with the introduction of e-mobility.

The thesis has been conducted at the plant and production engineering department at AVL List GmbH. This department focuses on the cost calculations for the entire manufacturing processes of the major components of the powertrain. It also deals with the development of the cost engineering models, which help to estimate the exact costs of a major component. This thesis aims to clarify a best-cost country sourcing approach for electric vehicle components. The main aim is to find out the potential parts, which can be supplied by the best-cost countries for battery electric vehicles. Therefore, a cost model is applied for the battery pack manufacturing of a battery electric vehicle.

The collaboration with AVL List GmbH for the master thesis provides insight into the latest development of the technologies in the field of e-mobility. The cost model shows

[5] Klug, F. (2013), pp. 1-3

[6] https://www.avl.com/web/guest/company

the potential of strategic sourcing for the battery packs and its cost implications. This provides the company an insight into the sourcing and supply chain strategies for the battery electric vehicles.

1.2 Electric vehicle industry – Background and current players

The introduction of an electric car has its roots back in the 1830s, which was built in Scotland.[7] It used a non-rechargeable battery and the limited charge of the batteries prevented its further use. Later on, with the discovery of the rechargeable lead-acid batteries, the electric vehicles had become quite a mainstream mode of transport. This was evident when the New York City had a fleet of electric taxis. Almost 40% of the cars in the United States of America were electric.[8] Although this time was short lived as the invention of the electric starter made the internal combustion engines more popular. New oil discoveries in combination with the Henry Ford’s production innovations were instrumental in the emergence of the internal combustion engine vehicles.[9]

The electric cars never vanished, although the use was very limited. The oil crisis sooner helped in the development of new electric vehicle concepts.[10] OEMs like Ford, General Motors, Nissan, Toyota and Honda soon joined the production of limited electric vehicles. Today the major number of challenges and conditions has motivated the OEMs to step in the electric car manufacturing. It seems that within a few years, all the auto manufacturers will have an electric car in their product portfolio. As far as now there has been a substantial increase in the production of Electric cars.[11] With the advent of cars like the Tesla Roadster, Tesla Model S, Nissan Leaf and Chevrolet Volt, the popularity of the electric cars is on a high.

[7] Dunn, M. (May, 2011), p. 1

[8] Dunn, M. (May, 2011), pp. 1-3

[9] Dunn, M. (May, 2011), p. 3

[10] Energy Information Administration. (May, 2011)

[11] OECD/IEA (2016), p. 4

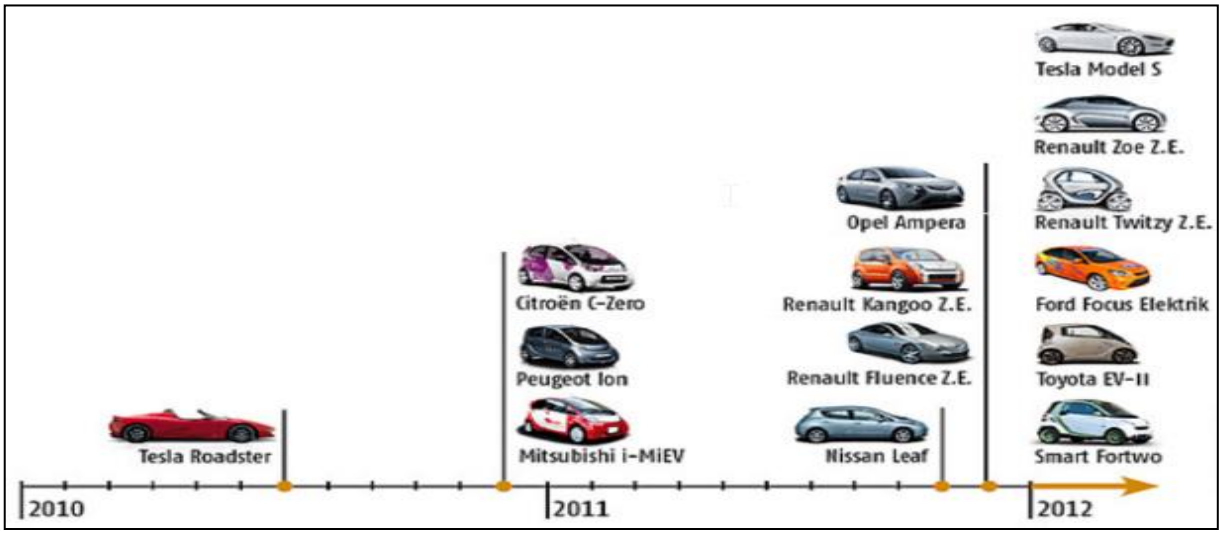

Figure 1.1 Entry of Electric cars in the global market[12]

Currently, every OEM is striving hard to be a market leader in the segment of electric vehicles. Even though the technology is still at a developing stage, the research, as well as market studies, show that the countries like USA, Japan, and China are the early adopters of the electric vehicle technology.[13] On the other hand, the European carmakers are the latecomers to the technology. The following graph illustrates, the evolution of the global electric car stock.[14]

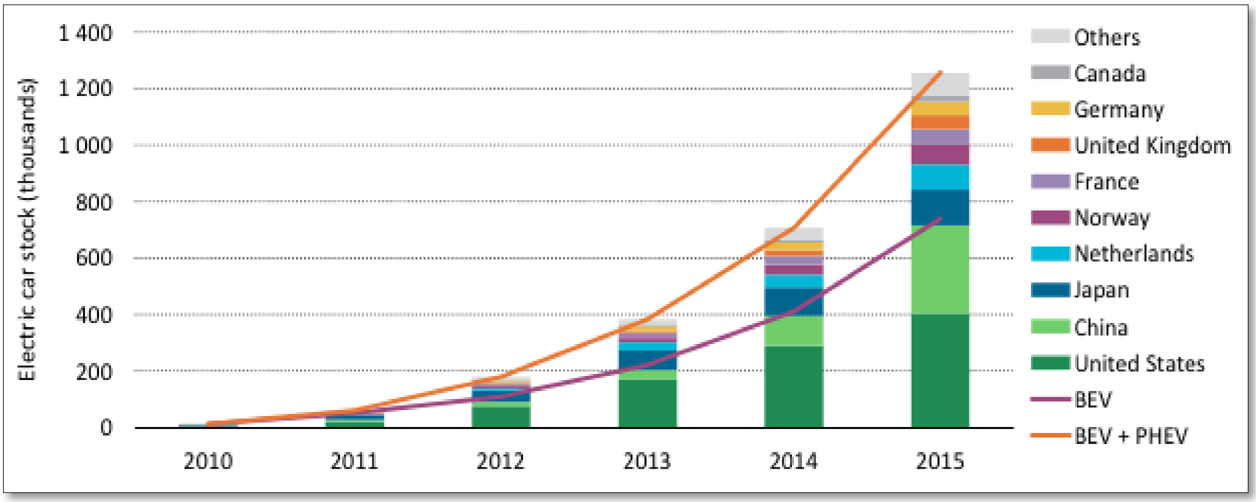

Figure 1.2 Evolution of global car market[15]

[12] ERTRAC, (May, 2011)

[13] OECD/IEA, (2016)

[14] OECD/IEA (2016), pp. 4-5

[15] OECD/IEA (2016), p. 4

However, the graph also depicts the significant efforts and achievements by the automakers and the governments jointly over the past years. Both of them have succeeded in effectively increasing the number of electric cars around the world. The market shares of electric cars in the year 2015 have almost doubled from the previous year. The policies, infrastructure, and other benefits are encouraging the OEMs to invest and deploy the electric cars in the market. In the longer run, there needs to be a greater support in order to achieve the goal of electric mobility and its worldwide adoption.[16]

There are various challenges in the process of achieving the goal of electric mobility. One of them is the high battery cost. Although the battery costs have decreased compared to the earlier costs, it still needs to be decreased further in order to decrease the overall cost of the car. The technological advancements in the battery should also be looked upon in order to get high ranges. The charging infrastructure is also one of the areas where development is needed. In order to overcome these challenges, there needs to be an efficient supply chain throughout the industry.[17]

1.3 Aim of the thesis

With the advent of the electric cars, the automotive supply chain is being transformed completely.[18] The transition to the electric cars has changed the level of logistics, production systems, supplier networks, and other related industries. The supply chain is one of the critical elements in the electric car industry for the OEMs.[19] In order to compete, the OEMs need a far better supply chain. The main objective of the thesis is to investigate the new supply chain for the electric car manufacturing. With the new technological advancement, the opportunities for the newcomers in the supplier industry, new capabilities, and other infrastructure requirements are on a high. The focus of the thesis is on the new supplier networks, differences to the traditional supply chains and best cost country sourcing for some of the important components for the electric cars such as battery cells and packs, e-motor and electric powertrain. The

[16] OECD/IEA, (2016), pp. 4-5

[17] Dunn, M. (May, 2011), pp. 1-3

[18] Klug, F. (2013), pp. 1-3

[19] Klug, F. (2013), pp. 1-3

objective, therefore, leads to investigate deeper into the concept and addresses the research questions.

In this report, two main leading questions are being addressed which helps to understand the value chain in the electric car industry. It also aims to point out the key role of the best-cost providers in the supply chain and how strategic sourcing can have an effect on the total cost of the battery packs.

What are the characteristic effects on the supply chain of a battery electric vehicle compared to an internal combustion engine vehicle?

The electric vehicle manufacturing process differs a lot from the conventional internal combustion engine vehicle manufacturing. This is with regards to the different components used in the vehicle. Consequently, the supply chain has a greater impact on manufacturing.[20] The OEMs need to have a superior supply chain in order to differentiate them from the competition. The aim is to figure out the impact on the supply chain of electric vehicle manufacturing and how it restructures the complete automotive supply chain. It also focuses on the various components, which have replaced the traditional mechanical parts of the internal combustion engine vehicles. These include components like battery cells and packs, electric motor, electric powertrain, inverters, and converters. The main emphasis lies on the supply of these components, the new supplier network and the value added to the vehicle due to the inclusion of these components.[21]

Which potential parts of the battery electric vehicle can be strategically sourced from best-cost countries?

Best-cost country sourcing approach has been very helpful for the OEMs to achieve lower manufacturing costs.[22] The lower labor costs, high flexibility, scale, and scope are some of the factors, which are influencing the process.[23] In the case of the electric vehicles, best-cost country sourcing can help to reduce the high costs of the components such as the battery packs. One of the major challenges faced by the

[20] Klug, F. (2013), pp. 1-3

[21] Dunn, M. (May, 2011), pp. 1-3

[22] Min, H. (July, 2011), p. 311

[23] Eriksson, H. & Lerenius, J. (2004), p. 9

OEMs is the reduction of high battery pack costs. The aim is not only to achieve lower costs but also keep in mind the quality of the components. This question mainly helps to identify the potential all around the globe for the development of the electric vehicle technology and strategically source these technologies in the form of the components.[24]

1.4 Methodological approach

The methodology used in the master thesis is combined with the qualitative and quantitative analysis. The qualitative analysis consists of the theoretical concepts and cases from the research papers and journals. On the other hand, quantitative approach is more of the practical approach. It consists of the structured data, which have been gathered by one or two ways and will be discussed later in this section.

1.4.1 Qualitative analysis

Qualitative analysis allows getting a deeper insight into a concept. It represents the theoretical data set, which is required to get an understanding of the topic. The ways of collecting the data are mostly through interviews and observations. These ways are helpful in getting the practical experiences at the research as well as industrial level. It can also be more flexible as compared to the quantitative analysis. The advantage of such a type of an approach is that the research layout can be changed during the progress of the work. However, it can be difficult to find an exact solution on the basis of the data collected.

This master thesis consists of multiple sources of data, which allows reviewing all the information. More emphasis is given on the holistic approach of the analysis rather than focusing on the surface context. The qualitative analysis also uses some quantification of the data in the context of some research points. The data used in such an approach defines the underlying concepts of the supply chain network for the battery electric vehicle manufacturing. This analysis consists of direct quotations from the participants of the master thesis in the form of interviews.

1.4.2 Quantitative analysis

The second type of an approach used to address the research questions is the quantitative analysis. Quantitative analysis as the name suggests concentrates more on

[24] Eriksson, H. & Lerenius, J. (2004), p. 9

the data that can be measured in real numbers. This is one of the important approaches in order to get a specific result based on the quantity. The master thesis consists of a manufacturing cost model of the battery packs for the battery electric vehicles. This approach helps to find out the necessary data to calculate the various types of costs included in the model.

In comparison to the qualitative analysis, this is a far more structured way of getting the data. It is based on the real values and interpretations. The cost model needs more specific data in terms of values and boundary parameters, which is provided by this approach. The data is useful to compare the results at different stages of the thesis. The different types of data collection methods will be discussed ahead in the chapter. These methods have been implemented during the research analysis and to obtain conclusive results.

1.4.3 Data collection

Several methods have been used to gather the required data and information during the thesis. The different techniques have been useful to get efficient and effective results. The different types of data collection methods such as interviews, literature research, surveys and the internal data collection can be discussed as follows.

a. Interviews

The interviews form an important source of data, as these are the experiences and information collected in the real time. As mentioned earlier, the thesis has been conducted at AVL List GmbH. Interviews were conducted at AVL List GmbH with some of the managers responsible for the electrification of the powertrain. These interviews were structured and unstructured interviews. The structured interviews involved the questions, which were provided well before the interview. These types of interviews provided a well-structured solution and deeper information. On the other hand, unstructured interviews were conducted spontaneously. These types of interviews were similar to a discussion about the strategies and results. There were also questionnaires, which were sent to the suppliers and other companies involved in the electric car industry.

b. Literature research

One of the important data used in this thesis is the literature research. Many articles, journals, and books have been referred, to collect important data, which have been used in the thesis. The information collected is mainly in the areas of supply chain management, battery electric vehicles and cost modeling. Many other different research projects have also been followed and taken reference from, to get a deeper insight into the research topic.

c. Internal information

Another important source of information used is the internal information at AVL List GmbH. The information such as cost calculation techniques, benchmarking data and the different strategic information has helped to find desired results and solutions to the research questions.

2 Electric vehicle – principle and working

This chapter covers the theoretical concepts of the master thesis report. Firstly, it comprises the working principle of the electric vehicle with the various components and it's functioning. It provides an insight into the important components of the vehicle, which eventually drive the supply chain. The concept also briefs about the differences between the working principles of traditional internal combustion engine vehicles compared to the electric vehicles. The principle for electric vehicles differs largely with respect to the internal combustion engines. Most of the mechanical components are replaced with the electronic and electrical components.

As the name suggests, electric vehicles are those, which are powered by the electric motors for propulsion. The electricity source for the motor is the battery. The basic difference between a gasoline-powered car and an electric car is that the power source is the battery rather than the gasoline, which delivers the mechanical power.[25] In an electric vehicle, the traditional gasoline engine is replaced with the battery, a motor, and a controller.

2.1 Key start and drive

In the initial phase of the drive, the 12V lead acid battery supplies the current to the engine auxiliaries and other electronic parts. This induces a charge in the lithium-ion battery pack, which is then transferred to the controller. The controller utilizes the power from the batteries and delivers to the electric motor. The electric motor thus transmits the power to the wheels, which drives the electric vehicle in the forward direction.[26] Figure 2.1 shows the initial phase of the working of an electric vehicle.

[25] Þuríður Björg Guðnadóttir. p. 7

[26] Volkswagen group of America (July, 2013), pp. 23 - 24

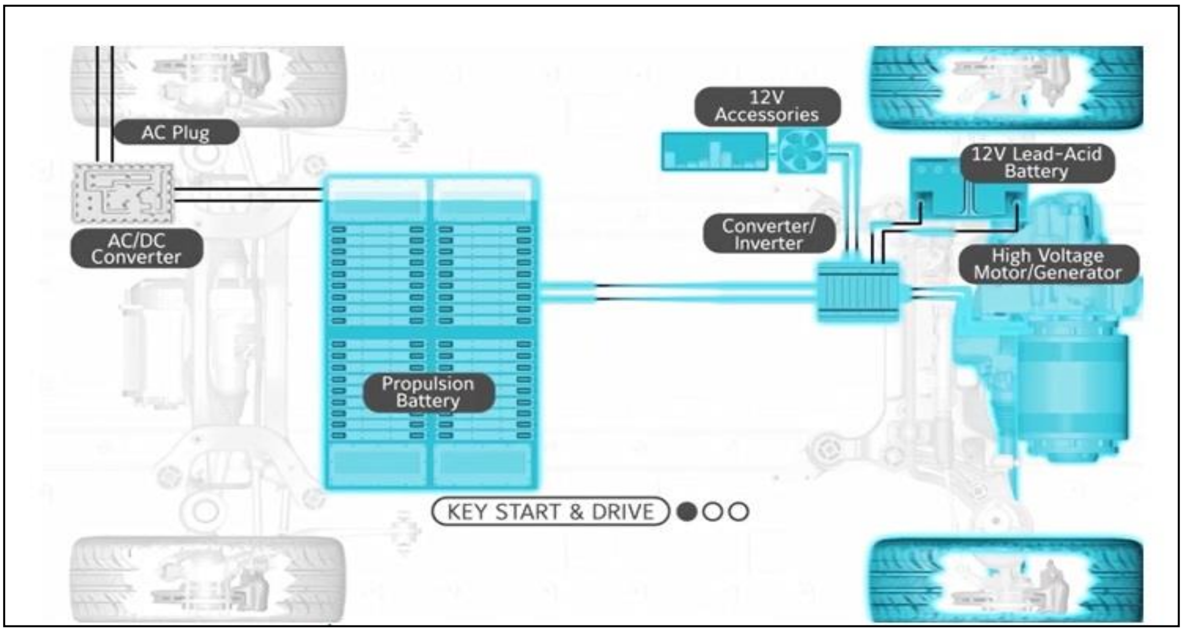

Figure 2.1 Key start and drive for electric vehicle[27]

2.2 Braking recovery

The second phase of the working principle of an electric vehicle is the regenerative braking. During braking, the motor acts as a generator and supplies the charge to the battery.[28] This helps to regenerate the lost energy in the braking and also helps to improve the battery performance. The diagrammatic representation is shown in figure 2.2.

[27] Johnson Controls Electric vehicle animation

[28] Toyota Motor Corporation (May, 2003)

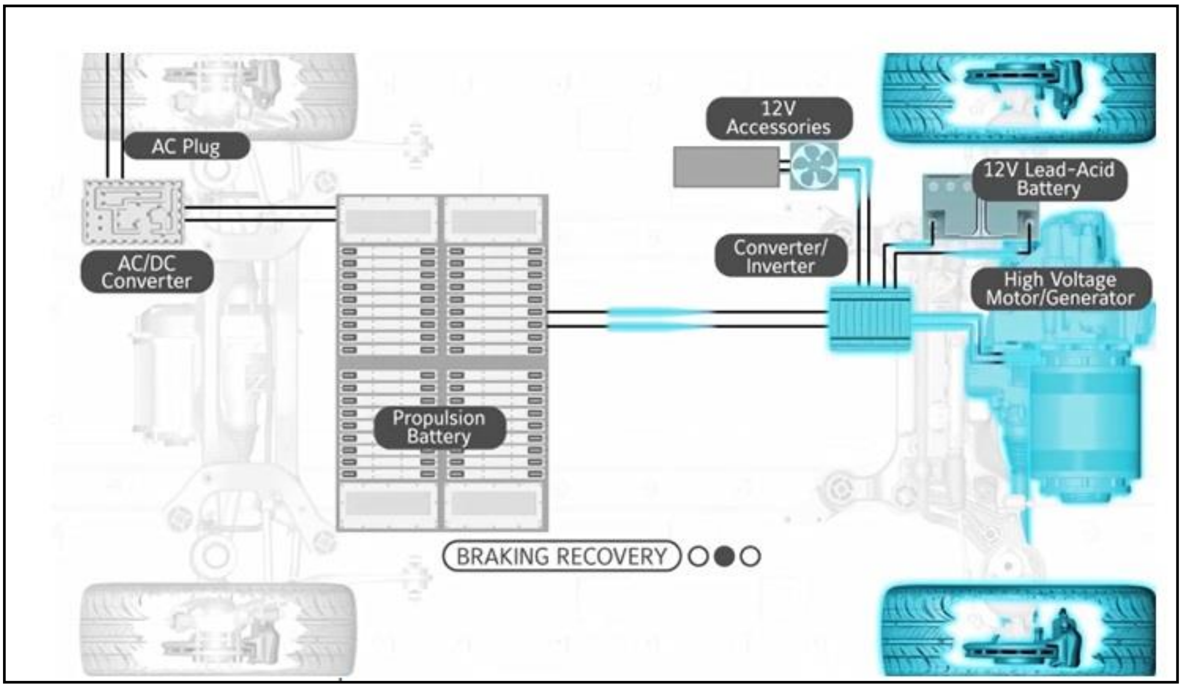

Figure 2.2 Braking system in electric vehicle[29]

2.3 Charging

The third operation in an electric vehicle is the charging system. The source of the electricity for the battery charger is the AC source.[30] This is converted to the DC source with the help of a converter. The converter thus supplies the DC source of electricity to the battery pack, which results in the charging of the battery pack. The battery chargers regulate the current and voltage with the help of advanced systems.[31] On the other hand, the standards for charging the electric vehicles are different in different countries. A diagrammatic representation of figure 2.3 shows the charging process in the electric vehicles.

[29] Johnson Controls Electric vehicle animation

[30] Larminie, J. & Lowry, J. (2003), p. 48

[31] Bakker, D. (August, 2010)

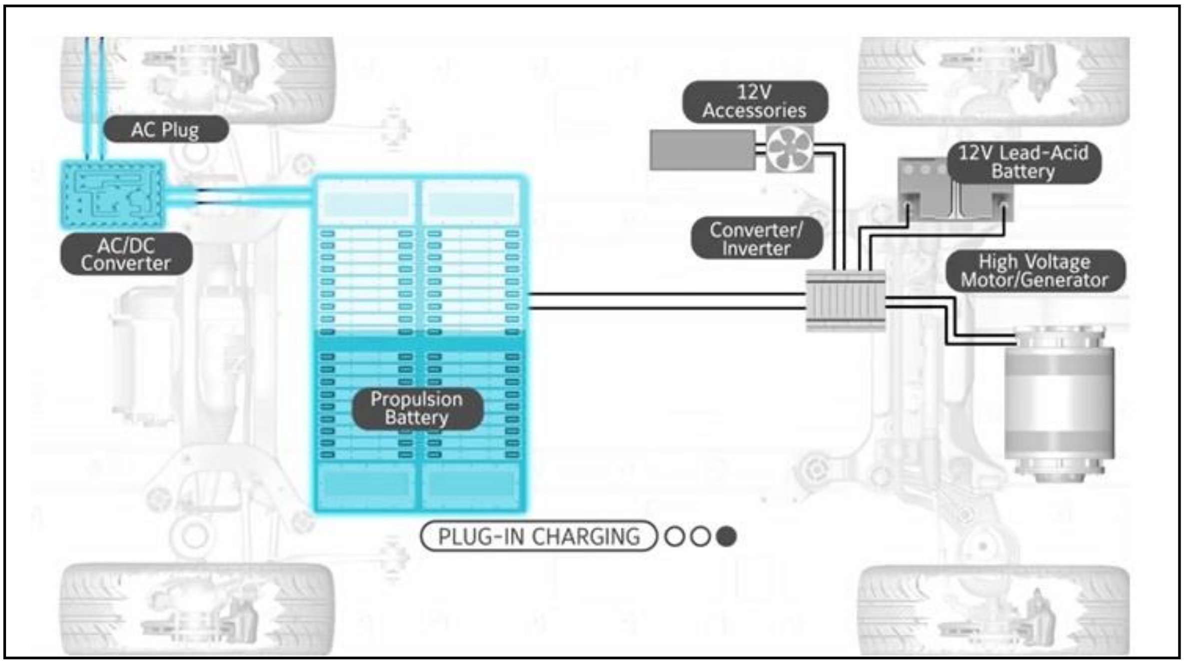

Figure 2.3 Charging in electric vehicle[32]

[32] Johnson Controls Electric vehicle animation

3 Types of electric vehicles

There are several types of the electric vehicles depending upon the powertrain.[33] Apart from the main types of electric vehicles, there are other vehicles, which run on a different powertrain. Some of these vehicles run by the supply of power lines. A small battery is used in such type of vehicles and the overhead supply lines supply the electricity.[34] Examples of such electric vehicles are trams and trolley buses. Few are those which use the energy from solar radiation called as solar powered vehicles. Various energy storage devices such as capacitors and flywheels have been used for the automobiles. The energy stored in such devices is relatively small and hence the practical use is limited.[35] However, the main focus of the thesis is on the battery electric vehicles. The different types of electric vehicles are described as follows:

3.1 Plug-in electric vehicles (PHEV & BEV)

Plug - in electric vehicles (PEV) are those, which are recharged externally with the help of a charging source such as wall sockets. The electricity source is the rechargeable battery packs inside the vehicle. The plug – in electric vehicles are mostly divided into two subcategories: Plug - in hybrid electric vehicles (PHEV) and Battery electric vehicles (BEV).[36]

a. Plug - in hybrid electric vehicle (PHEV)

PHEVs serve the purpose of both the conventional hybrid electric vehicles as well as the battery electric vehicles. It uses the rechargeable batteries, which can be charged by plugging it into an external source of electricity. It consists of an electric motor as well as an internal combustion engine. These vehicles are based on different types of powertrain architectures. These architectures are series, parallel and combination of series and parallel.[37] The basic design of the PHEV is shown in figure 3.1.

[33] Volkswagen group of America (July, 2013)

[34] Larminie, J. & Lowry, J.(2003), p. 18

[35] Larminie, J. & Lowry, J.(2003), p. 19

[36] Melaina, M. & Helwig, M. (2014), p. 8

[37] https://en.wikipedia.org/wiki/Plug-in_hybrid

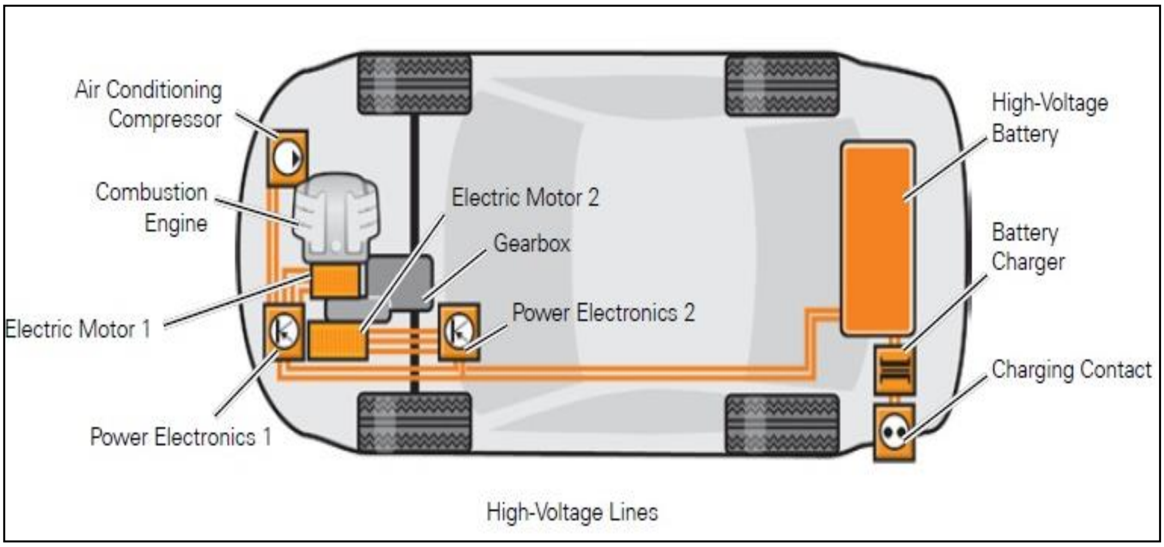

Figure 3.1 VW Golf 6 Twin drive Plug-in hybrid electric vehicle design[38]

The PHEVs function as a battery electric vehicle in order to increase the driving range. These vehicles are characterized by the larger battery packs compared to the conventional HEVs. In comparison to the HEVs, the PHEVs account for more cost savings on fuel. This is due to the recharging possibility of the batteries from the power grid.[39]

In series architecture for PHEVs, the motor solely provides power to the wheels whereas the internal combustion engine generates the electricity for the battery pack.[40] Chevrolet Volt is an example for the PHEV with series architecture. In the case of a parallel architecture, both the motor as well as engine are connected to the wheels in parallel. Mostly, the engine drives one of the axles while the motor drives the other as well as acts as a generator for recharging the batteries.[41] Honda Civic is an example for the PHEV with a parallel architecture. The combination of series and parallel architecture provides advantages with both the concepts. Such architecture is implemented in Toyota Prius plug-in hybrid model. On the basis of the driving conditions, these PHEVs operate either in a parallel mode or series mode.[42]

b. Battery electric vehicle (BEV)

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[38] Volkswagen group of America (July, 2013), p. 31

[39] Carley, D. (August, 2014)

[40] Nemry, F., Leduc G. & Munoz, A. (2009), p. 5

[41] Larminie, J. & Lowry, J.(2003), p. 11

[42] Nemry, F., Leduc, G. & Munoz, A. (2009)

The battery electric vehicles operate with the help of a motor and a rechargeable battery. It is independent of the traditional internal combustion engine. In order to recharge the battery, it is plugged into an external power source or a power grid. These vehicles are also capable of recharging the batteries on their own with the concept of regenerative braking. The battery electric vehicles are very different with respect to the traditional internal combustion engine vehicles as well as other electric vehicles. The types of battery electric vehicles vary from bicycles, scooters, and small electric cars to buses and delivery trucks. Most of the mechanical parts from the traditional internal combustion engine vehicle are replaced by the electrical and electronic components in a battery electric vehicle. Some of the spare parts such as exhaust systems are obsolete in the battery electric vehicles. One of the important points of BEVs is that these vehicles are zero emission vehicles.[43]

The main components of a battery electric vehicle are the motor, controller, and the rechargeable batteries.[44] The batteries are generally charged with the help of a power supply from the grid. The controller helps to convert the DC charge from the battery into AC charge and thus supplies power to the motor.[45] The motor, in turn, supplies the power to the transmission, which is then transferred to the wheels. As the electric motor develops high torque even at the minimum rpm, the battery electric vehicle doesn't require a complex transmission. A single gear ratio transmission system is used in the battery electric vehicles. Most of the electric vehicles use small motors, which are coupled to the wheel hub and act as an electronic differential. This helps to curb down the weight of the vehicle by using big conventional differentials and also reduces the number of mechanical components.[46] A simple architecture of a battery electric vehicle with its components is shown in figure 3.2.

[43] Larminie, J. & Lowry, J.(2003), p 8

[44] Holms, A. & Argueta, R. (March, 2011), p. 3

[45] Volkswagen group of America (July, 2013), p. 24

[46] Volkswagen group of America (July, 2013), p. 28

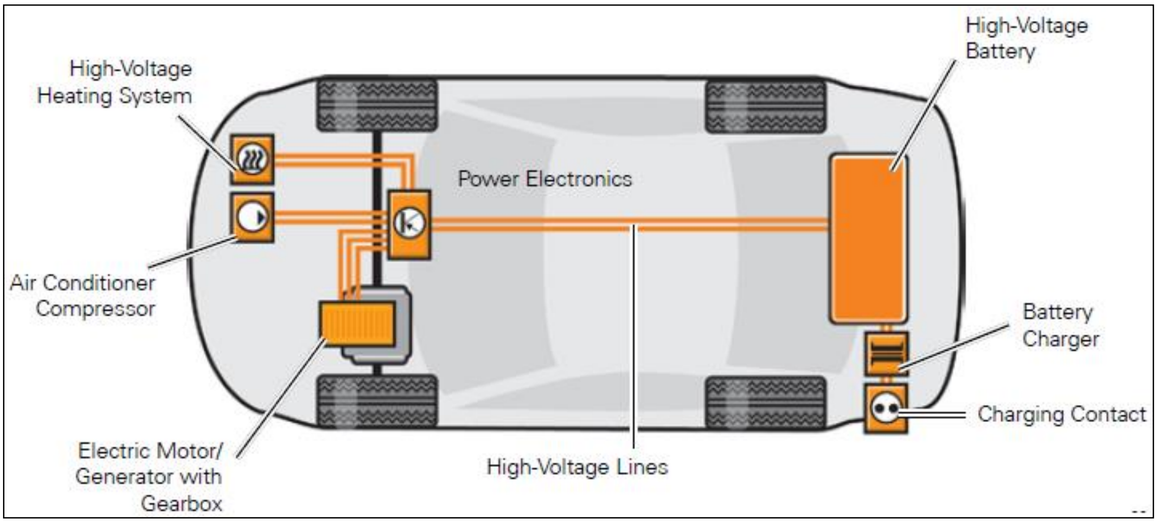

Figure 3.2 Design architecture for a BEV with its components[47]

3.2 Hybrid electric vehicle (HEV)

The working principle for the hybrid electric vehicles is similar to the plug-in hybrid electric vehicles. The main difference between these vehicles is the provision for recharging the battery for the PHEV. In the case of HEVs, the battery is recharged with the help of an engine or the generator used in the vehicle.[48] These vehicles are designed in order to achieve better fuel efficiency and increased power.[49] Similar to the PHEVs, the HEVs also consist of an internal combustion engine, a motor, a generator and a battery.

As discussed earlier for the PHEVs, the hybrid electric vehicle also uses different powertrain architecture types such as series, parallel and split combination. In a series combination, the motor independently turns on the transmission whereas the engine charges the battery. The vehicle is driven with the help of the motor supplied by the power from the battery or from the generator, which is coupled with the engine.[50] The entire driving force comes from the motor in a series arrangement. On the other hand, the parallel arrangement consists of the internal combustion engine placed in parallel to the electric motor. Both the engine and motor drive the transmission system.[51] The

[47] Volkswagen group of America (July, 2013), p. 34

[48] Larminie, J. & Lowry, J. (2003), p. 9

[49] Meyer, G., Dokic, J., Jürgens, H. & Stagl, S. (April, 2015)

[50] Larminie, J. & Lowry, J. (2003), p. 10

[51] Larminie, J. & Lowry, J. (2003), pp. 10-11

series and parallel architecture support the regenerative braking in order to charge the battery. Regenerative braking is a concept where the energy during braking is converted into electrical energy and stored in the battery.[52] Design architecture for a hybrid electric vehicle is shown in figure 3.3.

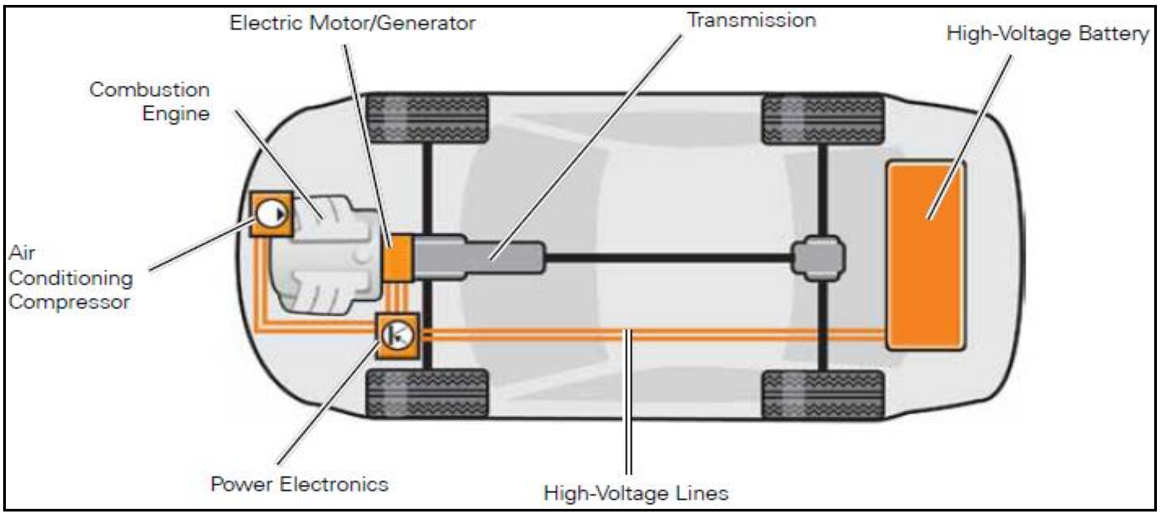

Figure 3.3 Design architecture for a HEV and its components[53]

3.3 Fuel cell electric vehicle (FCEV)

Fuel cell electric vehicles are one of the types of electric vehicle, which are becoming very popular now a day. These vehicles similar to the battery electric vehicles use an electric drivetrain for propulsion. The difference between these types of vehicles is that the fuel cell electric vehicles use a hydrogen fuel cell with a small battery to power the electric motors.[54] A fuel cell mainly uses hydrogen and oxygen in order to produce electricity to power the electric motors. The reaction between hydrogen ions and oxygen produces water. The released electrons flow in the circuit as an electric current. Thus the current is supplied to the electric motor for the propulsion of the vehicle.[55] The FCEVs are also termed as zero emission vehicles. The benefits provided by these vehicles are very similar to the battery electric vehicles.[56]

[52] Holms, A. & Argueta, R. (March, 2011), p. 5

[53] Volkswagen group of America (July, 2013), p. 29

[54] Johnson Matthey PLC. (August, 2013), p. 3

[55] Johnson Matthey PLC. (August, 2013), pp. 2-3

[56] Larminie, J. & Lowry, J. (2003), p. 15

In the case of a fully charged battery, the vehicle uses the supply of energy from the battery to the motor.[57] The fuel cell remains idle and does not supply any amount of energy. When the battery power is low, the fuel cell supplies energy to the batteries as well as the motor for running the vehicle.[58] The voltage supply to the battery from the fuel cell is 250V - 400V at an operating pressure of 3 bar.[59] The regenerative braking is applied with the help of the motor. It charges the battery during braking by working as an alternator. A basic architecture for a fuel cell electric vehicle is shown in the figure as follows.

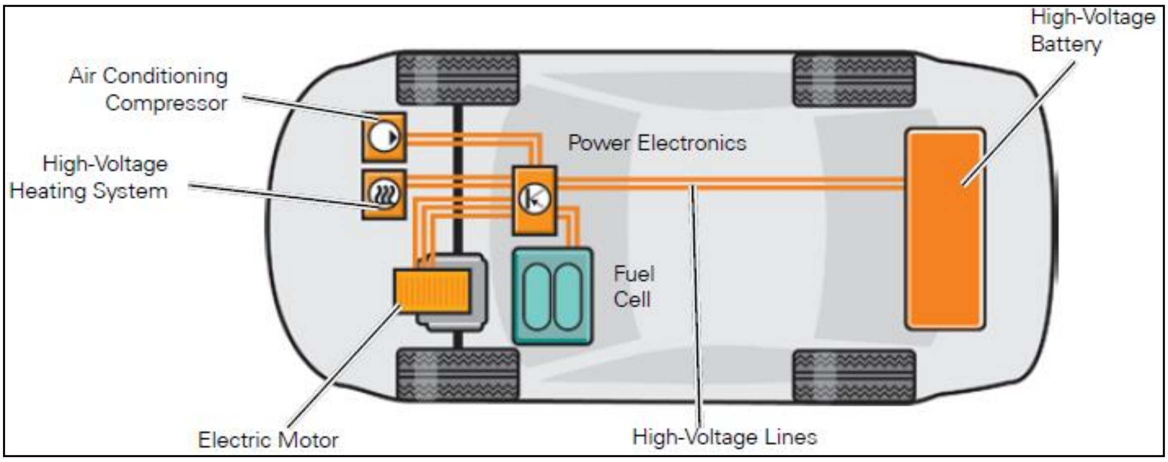

Figure 3.4 Design architecture for fuel cell electric vehicle[60]

[57] Volkswagen group of America (July, 2013), p. 39

[58] Volkswagen group of America (July, 2013), pp. 38-39

[59] Volkswagen group of America (July, 2013), p. 39

[60] Volkswagen group of America (July, 2013), p. 38

4 Battery electric vehicle components

The main focus of the master thesis is on the battery electric vehicles. In order to get a deeper understanding of the working of the BEVs, the components of the BEVs are discussed in this section. As discussed earlier, the main components of the battery electric vehicle consists of a rechargeable battery, an electric motor, and a controller. Besides these the other components include, power electronics, brake system, cooling system, battery charger, high voltage lines, and a cooling system. The section also covers the type of battery and motor used for the cost modeling of a battery pack. The detail concepts are discussed as follows.

4.1 Battery pack

The battery pack used in the BEVs is considered as the most important component. The most important characteristic of a battery electric vehicle is its energy storage capacity[61], which is determined by the type of the battery used in the vehicle. The energy storage capacity of a battery pack is an essential factor in determining the range of the vehicle.[62] There are various battery technologies used in the battery electric vehicles. Currently, lithium-ion battery technology is preferred over the other technologies due to its greater benefits. The types of battery technologies used such as lead acid, nickel – cadmium (Ni-Cd), nickel metal hydride (Ni-MH) are described as follows.[63]

a. Lead acid

The lead acid batteries are being used since a very long time in the automobiles. Due to its low specific energy, this battery technology is not preferred for the battery electric vehicles for longer ranges.[64] However, the lead acid batteries are available at a very low cost and they provide relatively good reliability. As the range and speeds are limited,

[61] Lowe, M. Tokuoka, S. Trigg, T. & Gereffi, G. (October, 2010), p. 12

[62] Lowe, M. et.al (October, 2010), p. 13

[63] Cluzel, C. & Douglas, C. (March, 2013), pp. 6 - 7

[64] Cluzel, C. & Douglas, C. (March, 2013), p. 6

these batteries are specifically used in small vehicles such as golf carts, forklifts and mobility scooters.[65]

b. Nickel – Cadmium (Ni-Cd)

The Ni-Cd batteries use nickel oxide hydroxide and metallic cadmium as the electrodes. These batteries have comparatively higher energy densities than the lead acid batteries.[66] The Ni-Cd batteries have a terminal voltage of 1.2 V, which is far less than the lead acid batteries.[67] Moreover, the material costs are also high compared to the lead acid batteries. One of the most important drawbacks of the Ni-Cd battery is the toxic cadmium metal which has a negative environmental effect. Due to these reasons, the use of Ni-Cd batteries is prohibited in the automobiles.[68]

c. Nickel-metal Hydride (Ni-MH)

The Ni-MH batteries are mostly used in the hybrid vehicles. In comparison to the lithium ion batteries, the Ni-MH have lesser energy densities**Error! Bookmark not defined.**. The nominal voltage is also far less than compared with the Ni-Cd as well as Li-ion batteries.[69] On the other hand, these batteries perform well in low temperature ranges which is from - 20 °C to - 40 °C.[70]

d. Molten salt

The molten salt batteries usually operate at the elevated temperatures i.e. 300°C.[71] The molten salt batteries include sodium nickel chloride and sodium sulphur. Due to the high operating temperature, the battery needs a heat source to maintain the temperature. This has an impact on the battery performance and hence these batteries are not used commercially. The sodium nickel chloride battery (NaNiCl) is also known as ZEBRA Battery (Zero Emission Battery Research).[72]

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[65] Cluzel, C. & Douglas, C. (March, 2013), p. 6

[66] Prange, S. & Brown, M. (1993)

[67] https://en.wikipedia.org/wiki/Nickel%E2%80%93cadmium_battery

[68] Cluzel, C. & Douglas, C. (March, 2013), p. 7

[69] International electro technical Commission. (October, 2010), p. 21

[70] International electro technical Commission. (October, 2010), p. 21

[71] Cluzel, C. & Douglas, C. (March 2013), pp. 7 - 8

[72] International electro technical Commission. (October, 2010), p. 23

e. Lithium ion

Today, the most preferred battery technology is the lithium ion battery due to its several advantages to the other battery technologies. These batteries are used in various applications such as mobile phones, laptops and electric bikes and cars. Lithium ion batteries generally have higher energy densities and nominal voltage compared to other batteries.[73] Lithium ion battery type is selected for calculating the manufacturing cost of a battery pack for the master thesis. The main reason for selection of the li-ion battery type is the advantages it offers with respect to other battery technologies.

4.2 Motor

The electric motors are used to convert the electrical energy from the battery pack to the mechanical energy used for propulsion. Various types of electric motors can be used in an electric vehicle for transmitting the power to the driving shaft and then to the wheels. These types are DC Motors, AC Induction motors and permanent magnet synchronous motors.[74] These motors are selected on the basis of various factors intended for the electric vehicle. The detailed concepts for the electric motors are discussed as follows.

a. DC Motors

These motors are popular in the electric vehicles. The source of the battery being DC makes it easy to use the DC motors for propulsion in the electric vehicles. In comparison to the AC Induction motors, the DC motors have simple construction and a much simpler controller. On the other hand, these motors are expensive and also heavier than the AC induction motors. The efficiency of the DC motors is approximately 85-95 % at full load.[75] The DC motors consist of two types of motors, namely the brushless DC motors and Brushed DC Motors. The brushless DC motors are preferred over the brushed DC Motors due to the longer span. However, the initial costs are high and need a complicated controller.[76]

b. AC Induction Motors

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[73] International electro technical Commission. (October, 2010), pp. 21 - 22

[74] Huang, Q. Li & J. Chen, Y. (2010), p. 3

[75] Idoho National Laboratory, “Advanced Vehicle Testing Activity”

[76] Huang, Q. Li, & J. Chen, Y. (2010), pp. 4 - 5

Currently, the AC induction motors are most widely used in the electric vehicles. The reason for its wide use is being its high efficiency and lightweight.[77] With the use of AC Motors, there is a need to introduce inverters in order to change the direct current from the battery to the alternating current. This increases the total cost of the AC motors. Due to the less moving parts inside the motors, it requires very less maintenance and lasts for a long time.[75]

4.3 Controller

The controller used in the battery electric vehicles operates between the battery and the motor in order to control the speed and acceleration of the vehicle.[78] The type of controller used for the battery electric vehicles mainly depends upon the type of the motor used. In case of the AC induction motor, the DC current from the battery pack needs to be converted to AC current, which is done by the DC to AC inverter. Meanwhile, the other controllers used are DC to DC converters, which provide a boost in voltage for the motors.[79]

[77] Huang, Q. Li & J. Chen, Y. (2010), p. 7

[78] Idoho National Laboratory, “Advanced Vehicle Testing Activity”

[79] Idoho National Laboratory, “Advanced Vehicle Testing Activity”

5 Supply chain management - concept

Supply chain management is a critical element for the OEMs in order to enhance the performance.[80] The demanding customer requirements and preferences have led the OEMs to the continuous improvements in the organizations.[81] A better supply chain management has been instrumental in providing a competitive edge to the OEMs.[82] The automotive industry has been changing over the period of time and therefore, a strong supply chain needs to be implemented across the industry in order to face the challenges.[83] The master thesis focuses on the supply chain network for the Battery electric vehicle manufacturing and its implications. Therefore, it is important to understand the basic concepts of supply chain management. This section covers the importance of supply chain management and the idea of implementing it in an organization.

Keith Oliver, an associate at Booz, Allen, and Hamilton, Inc., introduced the term Supply Chain Management in 1982.[84] The supply chain management includes all the areas of an organisation such as procurement, logistics, and distribution. It is basically the complete cycle of the movement of raw materials in an organisation, processing the raw materials into finished goods and distributing the goods to the consumer.[85] In other words, the supply chain management can be defined as the activities the product undergoes from the beginning to the end. It can also be said that the supply chain provides the material and information flow from the suppliers to the customers. This requires a clear coordination between the suppliers and the customers. Thus the supply chain is segmented into various forms for a better execution.[86]

In order to achieve cost reductions, improve quality and streamline the operations, the necessary step is the integration of processes. The supply chain involves many such

[80] Lešková, A. & Kováčová, L. (July, 2012), p. 97

[81] Schwarz, M. (2008), p. 1

[82] Lešková, A. & Kováčová, L. (July, 2012), p. 97

[83] Schwarz, M. (2008), p. 5

[84] Heckmann, P. & D. Engel, H. (2003)

[85] Plattner & Leukert. (2015), p. 15

[86] Plattner & Leukert. (2015), pp. 15 - 16

key processes. The key processes that comprise the core of supply chain management are depicted in the figure as follows:[87]

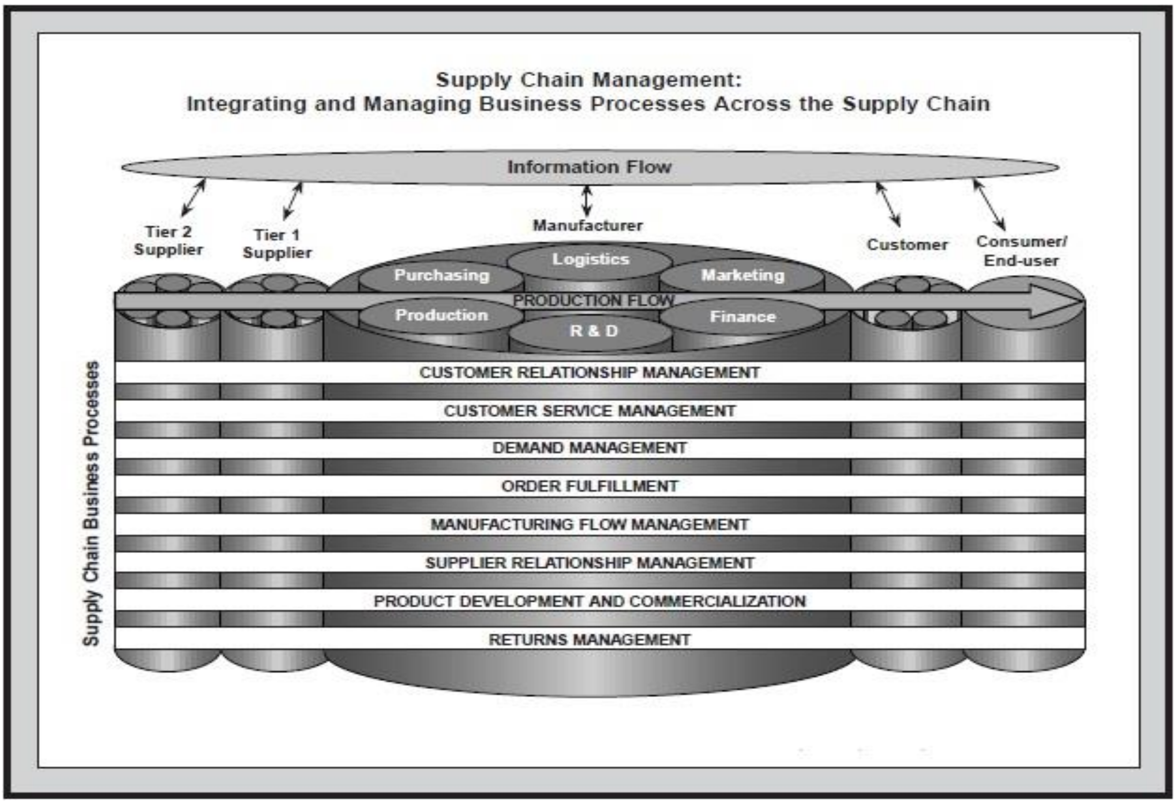

Figure 5.1 Business processes across supply chain management[88]

The key processes mentioned above are relatively important in defining the supply chain management process. These processes operate at the strategic as well as operational levels in an organisation. The interdependency of these processes involves many other functional areas such as Marketing, Finance, Research and Development, Production, Purchasing, and Logistics.[89] The processes have been discussed in detail in order to get an idea of the impact of the processes on the various functional areas. The integration of these processes within the functional areas and the supply chain is also discussed.

5.1 Customer relationship management

The integration of customer relationship management in the supply chain process helps to benefit the organisations not only in a financial way but also with respect to the

[87] Croxton, K. García-Dastugue, S. & Lambert, D. (2001), p. 14

[88] Croxton, K. García-Dastugue, S. & Lambert, D. (2001), p. 14

[89] Croxton, K. García-Dastugue, S. & Lambert, D. (2001), pp. 14 - 16

competition. The organisations are able to achieve numerous good results in the areas of marketing, sales and customer service.[90] The customer relationship management mainly deals with the development and communication with the customer. The next step comprises of segmenting the customers into groups and identifying the criteria in order to categorize the customers. The management team further reviews the customer position in the industry, the sales growth and the number of products purchased.[91]

5.2 Customer service management

The actual face of an organisation to the customer is the customer service management. This area deals with various customer information such as shipping dates, product availability and the order status of the product. The customer service management deals with the planning and management of the products and services to the customer. This area is one of the key points of contact with the customer. The team develops the response procedures to the customers. In order to execute this, it helps to identify the infrastructure required for the series of events. This mainly involves developing the means of communication with the customers. The team is responsible for communicating the internal as well as external events to the customer. Thus the cross-functional team involved helps to determine the events and solve the issues efficiently.[92]

The customer service management process also involves monitoring the process and evaluating the performance during the process.[93] It helps to get a future reference in order to resolve the similar kind of issues. The customer is also informed regularly about how the problem is being solved. All the information and the evaluation are then transferred to the supplier relationship management team as well as the customer relationship management team.

5.3 Demand management

One of the key processes in the entire supply chain is the demand management. Demand management is a methodology to plan and manage the requirements of the

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[90] Kracklauer, A. Mills, D. Seifert, & D. Barz, M. (2004)

[91] Croxton, K. García-Dastugue, & S. Lambert, D. (2001), p 16

[92] Croxton, K. et al. (2001), p 18

[93] Croxton, K. et al. (2001), p 18

customer with respect to the organisation's supply capability.[94] The team helps to understand, how to meet a certain requirement of the products from its customers and fulfils those requirements. This requires good forecasting techniques, coordination with the purchasing, production and sales department. Improving the operational activity and reducing demand fluctuations are one of the important tasks of demand management. Therefore, it is necessary to define the forecasting methods to be implemented in demand management, aligning it to the customer requirements. The goal of the demand management is to meet the customer demands in an efficient way.[95]

Demand management has a significant effect on the profitability of an organisation, customers, and suppliers. It helps to build a good relation with its customers. Precise forecasting methods can help to reduce the inventory, in turn reducing the costs.[96] The operational activity would help in the efficient logistic process and proper utilization of the resources. This helps to improve the efficiency across the entire supply chain. The Production planning and control, procurement and logistics department are the key functions, which are responsible for the efficient implementation of demand management. The production planning and control department ensures an effective planning with respect to the demands from the customers. These plans are then carried forward for procurement of materials, which is accomplished with the help of a strong logistic network. Thus the departments play a major role in strengthening the entire supply chain network.[97]

5.4 Order fulfilment

Meeting customer requirements with the help of order fulfilment are one of the important factors in the supply chain network. This involves an integration of the functions such as marketing, logistics and production. One of the main aims of the order fulfilment is to find ways to reduce the total delivery cost to the customers with a timely fulfilment of orders. It also includes designing an efficient supply chain network so that the customer

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[94] De Castro Melo, & D. Alcantara, R. (2014), p. 1

[95] Croxton, K. García-Dastugue, & S. Lambert, D. (2001), p. 51

[96] Croxton, K. et. al. (2001), p. 53

[97] Croxton, K. et al. (2001), pp. 52 - 53

orders are met in the given schedule.[98] It depends largely upon the production capacity, delivery lead times and requirements of the customer.

The order fulfilment faces numerous challenges during its execution. Customer satisfaction, delivery schedules, efficient and effective logistics network and inventory management are the key challenges that are faced during the operation of order fulfilment.[99] Apart from these challenges, it is also necessary to see factors such as the location of the manufacturing plant, proximity of suppliers to the manufacturing location and the modes of transport for the product delivery. In the process of order fulfilment, the orders are first processed, generated, documented and then delivered to the subsequent function.

Subsequently, once the order is produced, they are loaded for shipment. All the activities related to shipping such as generating the invoice, documentation, and payments is performed by the order fulfilment function and the feedback is sent to the customer relationship management as well as supplier relationship management.[100] The post-delivery process is also seen in this division where the returns of the goods and payment receipts are accepted. In the event of accepting the rejected products from the customer, the returns management function is informed.

5.5 Manufacturing flow management

Manufacturing flow management deals with the manufacturing of the products and managing the flow of the product throughout the manufacturing process. The main aim of this process is to ensure that the organisation possesses the manufacturing related facilities and requirements with respect to the customer. This involves factors such as production capacity, planning, and the strategies. The strategies help to get a better understanding of how the manufacturing technology and the capacity can be used in order to meet the customer demands.[101] It is very important to define other factors, which influence the manufacturing flow such as the cycle time, lot size, process flows and the labour needed for the entire manufacturing.

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[98] Croxton, K. (2001), pp. 19-32

[99] Peerless Research Group. (2012)

[100] Croxton, K. et al. (2001), pp. 20-21

[101] Croxton, K. et al. (2001), pp. 22-23

The important aspect of the manufacturing flow process with respect to the supply chain is the coordination and strategies with its suppliers. It is imperative to know, which goods will be produced at the manufacturing facility and which are to be outsourced from the suppliers. This is discussed with the procurement department so that the management of raw materials can be done efficiently. Another important decision in the manufacturing flow process is the make to order or make to stock. Various inputs regarding this strategy are received from the product development and design department so that the lead times are adjusted to meet the customer demands. This is one of the important factors in order to have an efficient and effective supply chain.

5.6 Supplier relationship management

Supplier relationship management as the name suggests is the relationship established with the suppliers in order to achieve benefits and the needs of the customer.[102] The supplier relationship management plays a vital role in developing a supplier and meeting the exact needs of the customer. This involves continuous interactions with different suppliers, monitoring their improvements, process developments, and different procurement strategies. It is very important to define the particular supplier for a particular customer and how that supplier can best achieve the goals of that customer. The supplier relationship management can be described as a part of the procurement process, which helps to give a holistic overview of the supplier integration into the supply chain management.[103]

The very first process in the supplier relationship management is the segmentation of the suppliers according to the various factors in order to determine the key suppliers, which need to be integrated into the supply chain.[104] It is very important to know which suppliers would benefit the organisation so that they are categorized as the tier 1 suppliers. The criteria of the segmentation of the suppliers include a volume of the goods supplied by the supplier, quality of the goods, innovation level at the supplier end, production capacity of the supplier, a level of service to the customer, the stability of the supplier in the market and its profitability.[105] These factors are used to weigh the

[102] Procurement leaders (June, 2013), p. 1

[103] Procurement leaders (June, 2013), pp. 2 - 3

[104] Gindner, K. Rajal, M. Zimmermann, P. Tognoni, M. & Geismann, M. (2015)

[105] Croxton, K. et al. (2001), pp. 24 - 25

capability of the supplier and measure its importance. Each supplier is given a preference based on these measurements and this helps the organisation to identify its key suppliers.[106]

The main objective of the supplier relationship management is to develop a mutual benefit to both the suppliers and the organisation by value addition to the supply chain. The main benefits of integrating the supplier relationship management into an organisation are cost reductions, development and measurement of the supplier performance aligning with the goals of the organization, increasing innovation through supplier collaboration and strategic sourcing through a varied network of suppliers.[107] These benefits drive the organisation and prove helpful in building a stronger supply chain network. Thus the supplier relationship management forms an integral part of the supply chain management.[108]

5.7 Product development and commercialization

Product development plays a vital role with respect to the customers and suppliers for its integration into the supply chain management. As a supplier, one of the most challenging tasks is the availability of new product ranges within a short period of time. Therefore, it is essential for the suppliers to integrate the customers into their product development process. On the other hand, the time to the market plays a very important role in the new product development. This can be crucial for the organisations with a maximum number of new products in the market at a right place and a right time to be able to get a competitive edge.[109]

For an organisation, it is imperative to include its suppliers as well as customers in the product development process so that the time to market is reduced.[110] Sourcing and marketing strategies form an important part of the product development process. Various sources of ideas need to be generated in the first place, which includes customer feedbacks and reviews. The product development and commercialization

[106] Gindner, K. et al. (2015), p 4

[107] Gindner, K. et al. (2015)

[108] Croxton, K. et al. (2001), pp. 24 - 26

[109] Croxton, K. et al. (2001), pp. 26 - 28

[110] Croxton, K. et al. (2001), p. 26

team comprises of a cross-functional team along with its main customers and suppliers. The main target of the department is to develop as much as new products aligning with the customer needs with a minimum risk.[111]

5.8 Returns management

The final step in the supply chain process is the returns management. Returns management deals with returns of goods and reverse-logistics. Many firms neglect the importance of the returns management in the supply chain process, while it forms an important part of the supply chain management. Returns management has a broader impact on the relationship with its customers. It not only deals with the efficient returns of the goods but also with the improvement of productivity and minimizing the unwanted returns of the goods.[112]

The returns management process is handling of the goods that are returned from the customer. At the first place, a customer sends a returns request, which is received at the other end by the sender of the goods. The process follows with a reverse logistics in which the logistics routing is done. Upon the arrival of the product, the product undergoes inspection tests and processing. The next step determines whether the product needs to be returned to the supplier, warehouse, recycle or remanufacture.[113] This also deals with the supplier engagements where the possibilities of improvements are discussed. Finally, the exact reason for the return of the product is evaluated and the process is measured. The returns management helps in continuous improvements of product and process.[114]

5.9 Supply chain management integration

The processes discussed in the earlier section are very critical in the integration of the supply chain management. These processes help to build a stronger supply chain network among the organisation. It is very important to know which process needs to be implemented at a right point of time. Moreover, a right coordination between the cross-functional teams helps to strengthen the supply chain process and implement it

[111] Croxton, K. et al. (2001), pp. 26 - 28

[112] Mollenkopf, D. Russo, I. Frankel, R.

[113] Croxton, K. et al. (2001), p. 30

[114] Croxton, K. et al. (2001), pp. 29 - 30

effectively. The executives need to take many critical decisions, which help to achieve the goals of an organization by integrating a good supply chain.[115]

Each department plays a vital role in making the supply chain efficient and effective. The interdependency of these functional areas determines how strong the supply chain network is among the organization. For example, the purchasing department relies heavily on the data by the production planning and control department, which is then transmitted to the suppliers. This requires a good coordination between the two departments. Today, the industries are relying heavily on outsourcing and it has become a key element in the development of the organizations worldwide.[116] This requires a proper planning and coordination between different functional areas. Figure 5.2 describes the interrelation between the functional areas and the supply chain processes.

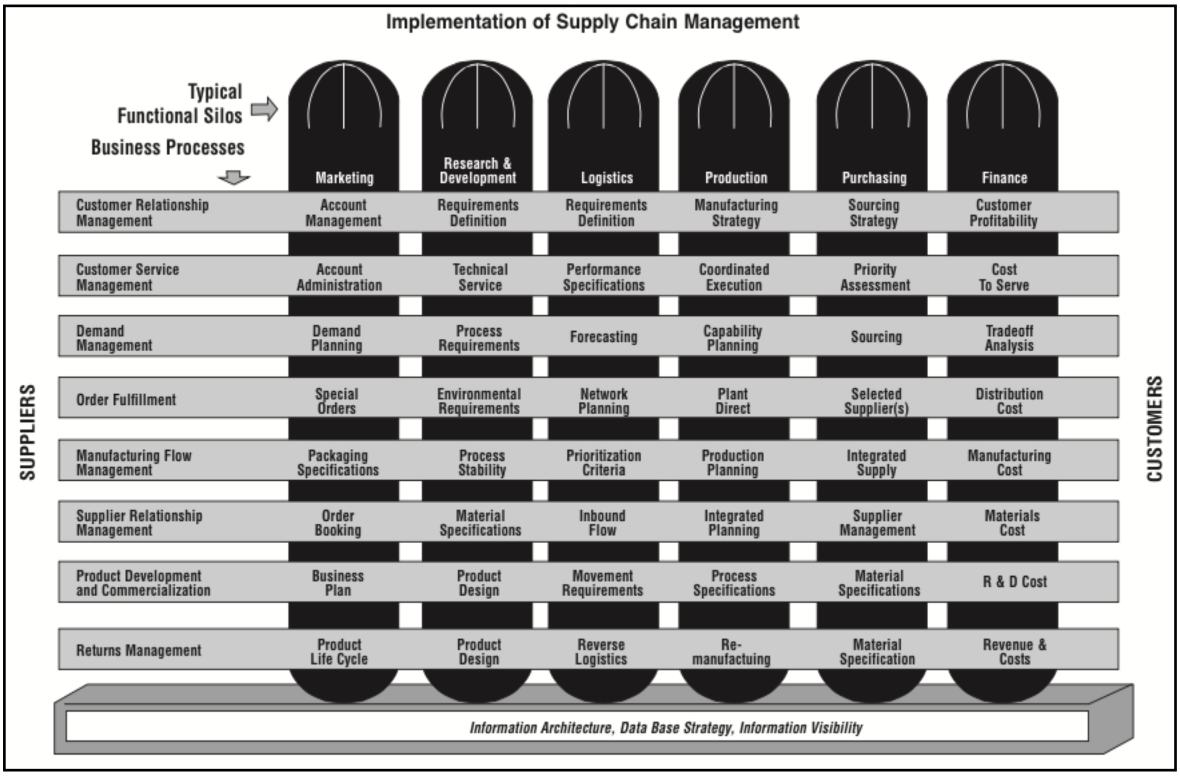

Figure 5.2 Supply chain integration[117]

[115] Croxton, K. et al. (2001), pp. 30-31

[116] Croxton, K. et al. (2001), pp. 30-31

[117] Croxton, K. et al. (2001), p. 35

5.10 Supply chain in the automotive industry

The supply chain in the automotive industry is similar to the processes in other industry as well. It is basically divided into the forward supply chain and reverse supply chain.[118] The forward supply chain consists of the main manufacturing processes and receiving raw materials from the tier 1 suppliers. The forward supply chain also involves the tier 2 suppliers who source the materials to the tier 1 suppliers. Some of the parts received at the tier 1 supplier are recycled through the recycling process. However, both the primary and the recycled parts are used in the value chain.[119]

The tier 1 suppliers are generally responsible for the assembly parts and components. These are manufactured and forwarded at the production site of the vehicles to the OEMs. The parts are then assembled at the production site to manufacture the entire vehicle. The vehicles manufactured are then sold through the distributors to the customers. This includes the sales in and outside the country.[120]

The reverse supply chain consists of usage of the old vehicles, which are sold back to the dealers and the distributors. The vehicles with no further shelf life are scraped and some of its parts are then recycled. The recycled parts are brought back to the raw material suppliers and can be used again for the vehicle manufacturing. These materials are passed ahead only when they meet the specific quality requirements.[121]

The supply chain for the automobile manufacturing also consists of an energy supply. This includes the energy supplied for the manufacturing of the vehicles through the local grid. The well to tank supply chain refers to the crude oil extraction and distribution of the fuel whereas the tank to wheel refers to the usage of fuel by the vehicles.[122] Figure 5.3 illustrates the supply chain structure for the automotive industry.

[118] Günther, O. Kannegieser, M. & Autenrieb, N. (November, 2014), p. 5

[119] Günther, O. Kannegieser, M. & Autenrieb, N. (November, 2014), pp. 5 - 6

[120] Günther, O. Kannegieser, M. & Autenrieb, N. (November, 2014), p. 6

[121] Günther, O. Kannegieser, M. & Autenrieb, N. (November, 2014), pp. 5 - 6

[122] Günther, O. Kannegieser, M. & Autenrieb, N. (November, 2014), pp. 5 - 6

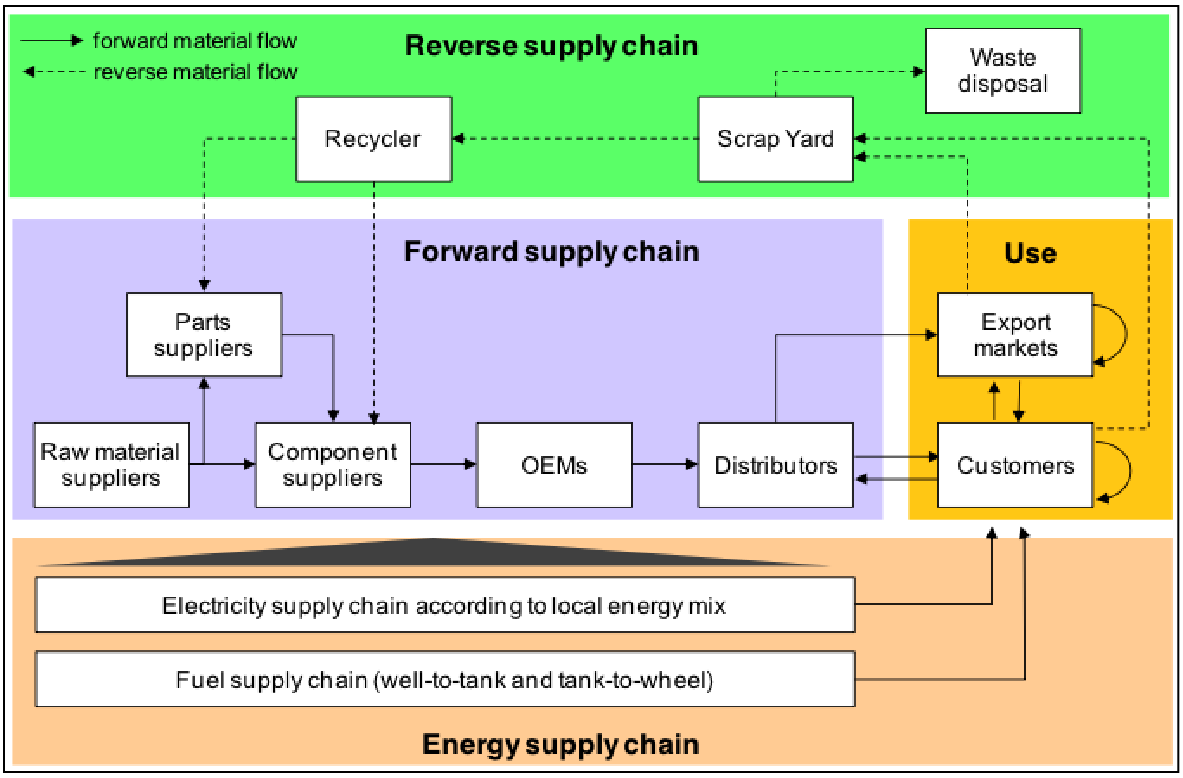

Figure 5.3 Supply chain in an automotive industry[123]

5.11 Lean supply chain

Lean supply chain is one of the strategies of the supply chain implemented in the automotive industry. The term Lean means activities to eliminate wastes, reduce the non-value added operations and improving the value added operations.[124] The main aim of lean supply chain is to improve the quality by elimination of the wastes. It also deals with the cost reduction and continuous quality improvement through minimum efforts. Lean thinking provides a feedback to the efforts; the value creating operations are performed sequentially without any interruptions, which leads to the effective performance of the operations.[125] Some of the wastes, which are highlighted in a manufacturing process, can be classified as follows:

a. Inventory

[123] Günther, O. Kannegieser, M. & Autenrieb, N. (November, 2014), p 6

[124] Wee, H.M. & Simon, Wu (2009)

[125] Womack, J. & Jones, D. (2003)

Inventory can be classified as a one of the wastes during a manufacturing process. High inventory can lead to higher costs and storage problems. Anything in excess can lead to huge loss for an organisation.[126]

b. Scrap / Rework

Defect in quality and manufacturing techniques can lead to scrap or rework. This can be in terms of the product quality or customer satisfaction. It can lead to excessive cost, increased labor work, and waste of time.[127]

c. Waiting

Longer waiting times are termed as one of the wastes. Machine downtime, bottleneck in the operations, changeover time, information from the customers or the suppliers are some of the causes of the longer waiting times.[128]

d. Motion

Movement of people towards the equipment, machine movement from a certain point, movement between certain workstations can cause such a type of waste. This leads to wastage of time, excessive costs, and stress in the workers.[129]

e. Transport

Transport of materials from one place to another can cause no value add to the product. The material flow should be without any delays from one process to another process. This can cause fewer delays on the shop floor. Complex handling of the materials and working in large batch sizes are few reasons for the transportation waste.[130]

f. Overproduction

Producing more than the customer demand can lead to overproduction. Overproduction leads to other types of wastes such as inventory. This causes huge amount of costs.

[126] Columbus, L. (2008), p. 2

[127] Womack, J. & Jones, D. (2003)

[128] Simboli, A. Taddeo, R. & Morgante, A. (May 2014), p. 178

[129] Columbus, L. (2008), p. 2

[130] Womack, J. & Jones, D. (2003)

Unreliable processes, longer lead times, unscheduled work plan can lead to overproduction.[131]

g. Over processing

Doing more amount of work than the required can lead to over processing. Unnecessary operations, bad quality control systems are some of the reasons for over processing.[132]

h. Intellect

One of the most important factors on the shop floor is the intellect of the employees. Not using the intellect of the employees is regarded as one of the wastes. The input from the employees can help add value to the activities. It can lead to improve the efficiency and eliminate all the wastes.[133]

In order to eliminate the above-mentioned wastes, there are some lean principles, which need to be followed. These principles with the help of some lean techniques and tools help to improve the efficiency at the work place, eliminate waste and improve the productivity. These principles can be summarised as follows:

a. Specify the value

The customer always defines the value of a product or a service. Any product or a service has a value only when it fulfills the requirements of the customer. The manufacturer does the value creation. Therefore, in order to add the value to a product or a service, the manufacturer must produce or offer a service, which suits the needs of the customer, at a specified requirement and price. This can be achieved by involving the customer in product development, process development and continuous customer feedbacks and dialogues. Thus, specifying value is one of the main steps in implementation of lean.[134]

b. Identification of the value stream

[131] Simboli, A. Taddeo, R. & Morgante, A. (May 2014), p. 178

[132] Simboli, A. Taddeo, R. & Morgante, A. (May 2014), p. 178

[133] Lean horizons Consulting (2008), p. 8

[134] Womack, J. & Jones, D. (2003), p. 29

The next lean principle is the identification of the value stream during a manufacturing process. Value stream can be defined as the set of the activities required for manufacturing a product or delivering a service to a customer. These set of activities constitute design of the products, engineering activities, scheduling of the production, delivery of the products or services, managing the material flow, conversion of raw materials into finished goods. Identification of the value steam helps to sort out the value added and non-value added activities. It also helps to eliminate the wastes during the manufacturing process and build a set of activities that provide value to the customer.[135]

c. Establishing flow

Establishing the flow of the value added activities into small groups through different departments and functions are one of the next steps in the implementation of lean principles. The activities are allocated to the different functions and departments, which help to create value individually to the products. This value flow is created through these functionalities and departments by integrating the system and building a relationship with the employees.[136]

d. Pull

Pull system is a lean principle where, the manufacturers produce exactly what the customers need, when the customers need and how much they need. This allows establishing a good relationship with the customer. It stables the customer demands, allows them to get whatever they need from the manufacturer. Creating a pull system also reduces high mounts of inventories, thereby reducing the other related wastes.[137]

e. Perfection

After specifying the value, identification of the value stream, mapping the flow of the activities, and creating a pull system, the last step is the perfection. This step involves all the four steps and evaluating the progress of these steps. One way of achieving perfection is being transparent in the activities. Some of the problem solving techniques also helps to achieve perfection in the process. Employee involvement and interactions

[135] Womack, J. & Jones, D. (2003), p. 37

[136] Womack, J. & Jones, D. (2003), p. 50

[137] Womack, J. & Jones, D. (2003), p. 67

are ways to deal with the problems encountered at the shop floor and improve the efficiency.[138]

The lean principles consist of some of the lean practices and tools, which help to implement lean thinking. These lean tools are Just-in time, 5S, Value stream mapping, Single minute exchange of dies, Total preventive maintenance, kanban system, and kaizen. These tools help to reduce wastes in the process and help to execute lean philosophy.[139] The table illustrates the lean principles with the corresponding practices and tools.

PRINCIPLES	PRACTICES	TOOLS / TECHNIQUES
Specify value	Information on customer need, Customer focus, value chain analysis	Customer involvement
Identify value stream	Value chain analysis	VSM, JIT, 5S
Establish flow	System organisation, strong relationship between functions	JIT, 5S, SMED, Small lot sizes, TPM
Pull	Production of customer needs, Strong relation with customer	JIT, Kanban system
Perfection	Problem solving	5Whys, PDCA, Employee involvement

Table 5.1 Lean principles with corresponding tools and practices[140]

[138] Womack, J. & Jones, D. (2003), p. 90

[139] Ugochukwu, P. Engström, J. & Langstrand, J. (2012)

[140] Ugochukwu, P. Engström, J. & Langstrand, J. (2012)

6 Manufacturing and supply chain network

There has been a significant change in the nature of globalization over the years. This is due to the fast changing world trends. In the early days, there weren't many companies who used to have multiple production sites. The complexity of the products was also low. The product portfolio of the companies was also not so broad as compared to the today's portfolios. With the changing world and its fast pace, the companies have realized the potential of going global. The supply chain has a greater role in this transition. The world has come closer than earlier and the customer requirements have substantially increased. Due to the increasing customer demands, the companies are going global and also growing in each and every sector.[141]

As a result, the flow of information has increased drastically and thus the companies with a superior supply chain are flourishing. Earlier, the source of a product was a single location, which was usually located in the west. Now a day, with the factors such as low labor costs, competitive edge in the market, favorable market conditions and improving the market position the companies have their production facilities in each and every corner of the world. Nevertheless, these companies have a very high-level supply chain network and coordination among themselves.[142]

The increasing customer demands have also been one of the major factors for globalization. Today, the companies actively participate the customers in order to improve and strengthen their product portfolio. The developing economy has also contributed to the fast growing manufacturing networks. The companies over the world manage to get more expert knowledge than before from the various parts of the country. The demands have increased exponentially which have broadened the network of supply chain over the world. This has also increased the dependency of the worldwide manufacturing networks on one another.[143]

The figure 6.1 illustrates the growing globalization over the past years. It shows the rise in the globalization over the years. It also depicts how the network of the supply chain has grown at a considerable rate over the years. In the later part of this section, the

[141] Schmidt, B. Heller, R. (2011), pp. 1 - 2

[142] Diederichs, R. (April, 2016), p. 9

[143] Watson, M. Lewis, S. Cacioppi, P. & Jayaraman, J. (2014), p. 1

opportunities for a company for establishing global manufacturing network are discussed. It also covers the necessary criteria for selection of a manufacturing site and the implementation of a global manufacturing site.[144]

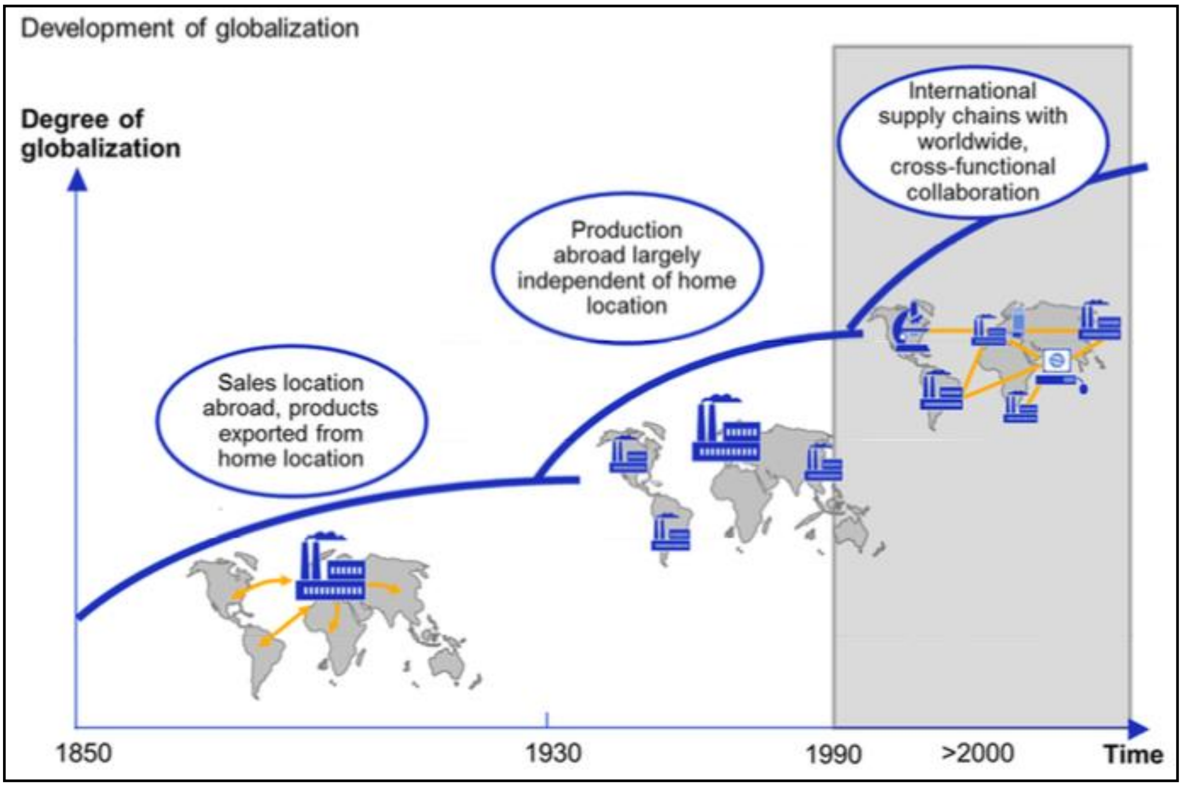

Figure 6.1 Development of globalization over the years[145]

There are many factors that need to be looked upon by the companies before going for a global production network. These factors enable the companies to grow and foster over a longer period of time. It is also important to look at several other aspects than the profits such as culture, geography and the talents. All such secondary factors can also have an impact on the companies with respect to its growth. All such factors will be discussed ahead in the report, which will provide a holistic view of establishing a global manufacturing footprint for a company.[146]

6.1 Global opportunities for a company

It is a very critical step to gauge the opportunities of a company in order to go global. It is essential to know that what are the number of advantages and disadvantages for a

[144] Diederichs, R. (April, 2016), pp 9 - 10

[145] Diederichs, R. (April, 2016), p 10

[146] Stank, T. Burnette, M. & Dittmann, P (2014), p 5

company before going for a global production. There are many factors, which need to be taken into account for such a planning. The foremost thing for a company to go global is to be aware of the market where it is going to compete.[147] The company must also know what should be its strategy to enter a particular market. The important drivers for the market entry and expansion should be one of the key factors for a company to go global.[148]

In order to start a manufacturing network, the other things, which follow, are the assessment of the unit cost of the product and the other corresponding costs such as logistics and landed costs.[149] The difference between the production costs in a new region compared with the earlier region gives a clear picture to start the manufacturing of the product globally. It provides the competitive edge the company will benefit by the cost difference. Besides the cost, the product specifications are also an important aspect in pulling the customers and making a strong market entry.[150]

The second step in assessing the company's opportunities for global production is to know and compare the competitor's product cost. The advantages and disadvantages will serve a good analysis and research for the cost of the product with respect to its competitor. Also, such a comparison can provide the company a cost advantage over the competitor's product. The product comparison helps to know if the product is competitive enough to enter the market with respect to the earlier products in the market. The product thus can be compared with respect to its competitor's product on the basis of cost, specifications, performance, design and material. One of the processes to do such an analysis is reverse engineering.[151]

The next step in gauging the company opportunities for a global production network is the market attractiveness. The market attractiveness of the product is an essential criterion for a company. The companies are always interested in investing in the emerging markets as these markets provide an opportunity for an exponential growth of the company. Thus it is important to know which markets need to be targeted for such a

[147] Schlegelmilch, B. B. (2016), p. 23

[148] Schlegelmilch, B. B. (2016), pp. 23 - 24

[149] Diederichs, R. (April, 2016), p. 13

[150] Diederichs, R. (April, 2016), p. 14

[151] Diederichs, R. (April, 2016), pp. 15 - 16

growth. The demands and the market competition need to be taken into account. The company needs to be familiar with the market and also understand the business in that particular market. The marketing and sales strategies need to be very well aligned with the company goals.[152]

6.2 Site selection for global manufacturing

The decision of selecting a site or a country for manufacturing is one of the core decisions and can be very complex. This includes a deep research and analysis by the company. Besides the labor costs, there are other influential factors as well which can affect the company's growth and sustainability. It is therefore ensured that all the other secondary factors are also taken into account before finalizing the site of manufacturing. Some companies also focus on the manufacturing of specific products. In such a case, profit is the most important criteria. Apart from the profitability, the breakeven point also needs to be considered.[153] Figure 6.2 indicates the list of the important factors, which need to be considered while selecting a site for manufacturing.

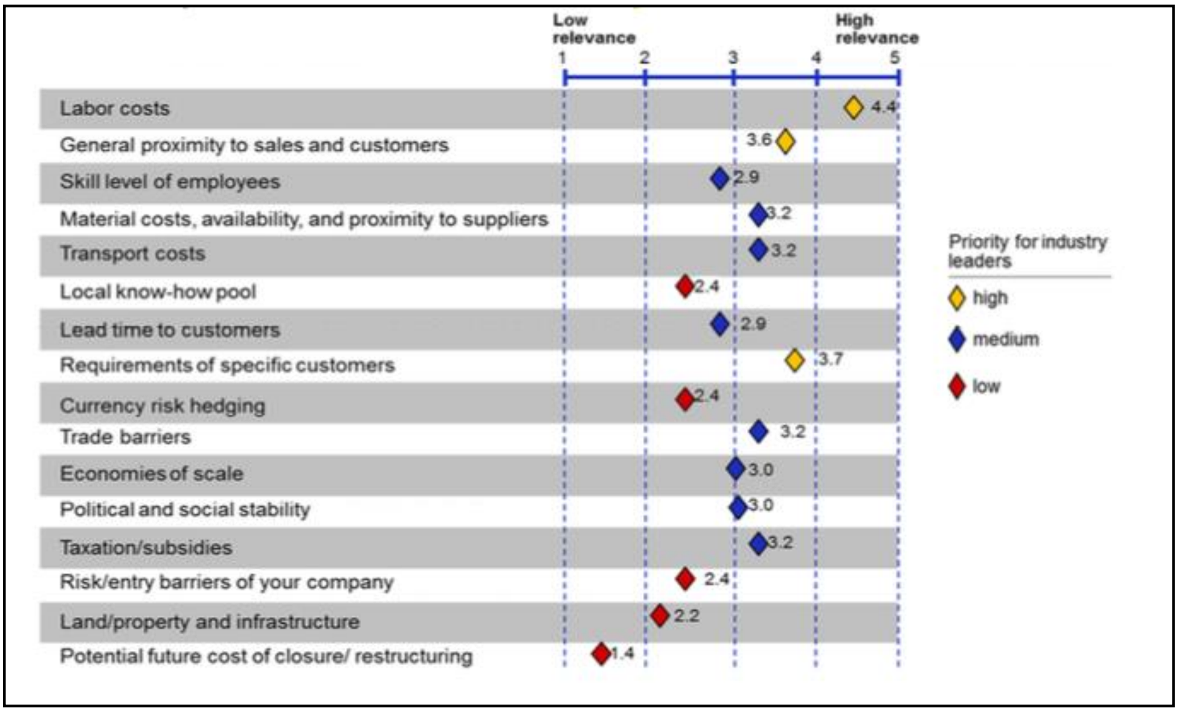

Figure 6.2 Factors influencing selection of a manufacturing site[154]

[152] Diederichs, R. (April, 2016), p. 33

[153] Kalantari, A. (August, 2013), p. 36

[154] Diederichs, R. (April, 2016), p. 35

The figure clearly shows that the influential factors for selecting a site are labor costs, customer requirements and the proximity to the customers. Apart from these high priority factors, other factors such as material costs, taxes, custom duties, economies of scale and transport costs are also important for the selection of the site. These factors are also considered and are given the appropriate weightage.[155]

Labor costs are one of the differentiating factors for a company to do its business in a best-cost country. It is therefore seen that the most of the companies are shifting from the developed region to the developing region. The developing regions are experiencing a tremendous amount of growth in each and every sector.[156] Thus in order to reduce the costs, the shift in manufacturing is towards the developing regions. For example, Apple Inc. does its designing work in California while the assembly work is done in China in order to achieve the lower labor costs. The other reason for this shift towards developing regions is the local talent. The local talent in the developing regions is also developing at a faster rate.[157]

There are some additional factors as well which need to be taken into account while selecting a site for manufacturing. These factors are the lead-time, delivery time, quality of the product, demand volatility and intellectual property protection.[158]

6.3 Implementation of manufacturing network

Implementation of the manufacturing network is one of the most complex processes while setting up a manufacturing site. This requires high skilled managers in order to ramp up the production activities. The complex production processes, unavailability of high skilled managers, integration of the process and a larger product range are some of the problems, which makes it more complex. In order to overcome such challenges, the company must define a proper strategy. One of the ways to overcome such challenges is establishing a joint venture with the local company. This would help to get

[155] Diederichs, R. (April, 2016), p. 35

[156] Abele, E. Meyer, T. Näher, U. Strube, G. & Sykes, R. (2008)

[157] Miller, H. (2010)

[158] Diederichs, R. (April, 2016), p. 38

know-how of the local market with the help of the local expertise. This largely depends on the partner company in case of a joint venture and the management skills.[159]

The implementation of a manufacturing network consists of many hurdles and milestones right from constructing the company to the final delivery of the product to the customers.[160] This process consists of procurement of materials, the construction process of the building, installation of the equipment, hiring people and another workforce. This process is a cost intensive process and therefore needs to be taken care of. Lack of planning can cause serious disturbances in the implementation of the manufacturing network. One of the important things for the implementation of a manufacturing network is ramp up activity.[161]

The main prerequisites for a successful implementation of a manufacturing network consist of following things:[162]

a. Experienced managers with a team

b. Training of employees

c. Expats

d. Local management team

e. Detailed planning

It is very important to have a right set of people at the right area for the successful ramp up production. The main factors are the recruitment of the expats, training of the employees and the knowledge sharing among the people.[163] It is also essential to keep in mind the costs while recruiting the expats, as the costs can be higher. It can be seen that how important the recruitment of a right employee can affect the ramp up activity.[164] Therefore, the important points to be noted when recruiting a top-level employee can be defined as follows:

[159] Dietz, M. Orr, G. & Xing, J. (2008), pp. 2 - 4

[160] Diederichs, R. (April, 2016), p. 51

[161] Diederichs, R. (April, 2016), p. 52

[162] Diederichs, R. (April, 2016), p. 53

[163] Kluge & Jürgen (2005)

[164] Diederichs, R. (April, 2016), p. 54

a. Cost / Wages

One of the important criteria when hiring an expat or a local manager is the cost. It definitely increases the cost expenditure but also pays off with the amount of knowledge and experience.[165]

b. Qualifications and expertise

The knowledge of the required field is a definite prerequisite when hiring an employee. In the case of local hiring, the employees can provide the right knowledge required for working in the local environment. The expats in such case can provide the expertise in accordance with the management policies. The combination of both can lead to an efficient way of working with the right things at the right place.[166]

c. Manufacturing knowledge

In case of deeper expertise levels, the manufacturing knowledge becomes a key criterion to possess for the high-level employees. In such a case, the local employees help to understand the dynamics of the local manufacturing, supplier network, and other such factors. While on the other hand, expats provide the standard practices and ways of manufacturing, which proves to be beneficial during the ramp up activity.[167]

d. Communication

Communication becomes a vital part in setting up a factory abroad due to major differences in language, cultures and working styles. A very good local support provides a strong integration of all the processes and reduces the barriers to the interaction between the local management and the corporate management. The expats also help in bridging this gap as the access to the corporate management is well within their reach.[168]

6.4 Building an efficient supply chain network

The last step in the implementation of a manufacturing network is to build an effective supply chain. This involves the even participation of the customers, manufacturers and

[165] Kalantari, A. (August, 2013), p. 38

[166] Kalantari, A. (August, 2013), pp. 39 - 40

[167] Diederichs, R. (April, 2016), pp. 53 – 54

[168] Diederichs, R. (April, 2016), pp. 53 - 54

the suppliers. The outflow and inflow of the goods is an important aspect in the supply chain. The flawless flow of goods eventually requires a strong supply chain network across the globe. A superior supply chain consists of a critical decision-making process. These decisions include logistics network, the location of warehouses, inventory control methods, transfer of goods and procurement.[169] Figure 6.3 shows the distributed network of a supply chain process across the globe.

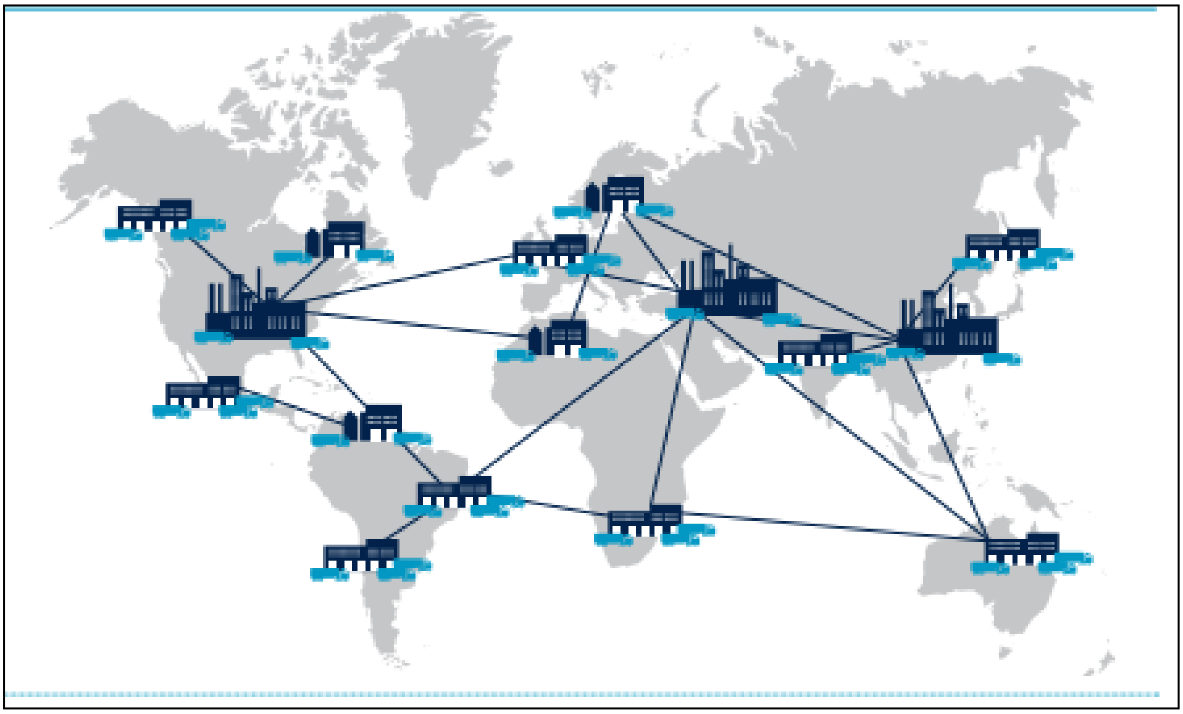

Figure 6.3 Global supply chain networks[170]

A superior supply chain network is very essential for a company's growth and sustainability. It plays an important role in meeting the ever increasing and dynamic customer demands. Therefore, the strategy needs to be very well aligned with the corporate goals in order to ensure success in today's markets. There are some key factors, which are required to implement in order to establish a strong supplier network. These factors will be discussed further.[171]

[169] Melo, M.T. Nickel, S. Saldanha-Da-Gama, S. (2008)

[170] Fancas, D. Simon, Z. (2011) p. 6

[171] Fancas, D. Simon, Z. (2011) p. 6

One of the ways to strengthen the supplier network is best-cost country sourcing.[172] This gives the organisation an edge in terms of cost savings. It has to be seen that the approval for such a process is received from the management board so that the advantages of best-cost country sourcing can be achieved. The hurdle in such a process is the change of the existing supplier network and building a new one in order to achieve cost savings. At the first moment, cost advantages are difficult to gauge but the future benefits are on the larger side.[173]

The subsequent step in the process is to integrate the best cost sourcing and build a standard aligning with the goals of the organization. The process requires many sub-processes like evaluating the supplier capacity, the machinery used at the supplier end, production processes, quality checks and inventory levels.[174] The integration of the suppliers requires full cooperation with the organization in terms of production processes and appropriate knowledge sharing. This helps in making the supplier relationship stronger as well as flexible with the organisation. The use of sourcing tools can make it easier for the organisation to involve the suppliers. One such tool used in the industries is the supplier relationship management tool (SRM).[175]

Building a supply chain network for a new manufacturing plant takes several years. This intensive process is carried out at a strategic, tactical and an operational level.[176] The strategic level mostly consists of building the supplier base and finds different methods to source the required materials. The tactical level deals with the means of transportation to the factory, warehouse and distribution centres for materials. This forms a linkage between sourcing and logistics process. At the operational level, the decisions are related to the production planning, maintaining the schedules for manufacturing and other processes at the manufacturing site.[177] Figure 6.4 depicts these three levels and the processes related to these levels.

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172 Nelson, D. & Sisk, K. (2005)

173 Nelson, D. & Sisk, K. (2005)

174 Diederichs, R. (April, 2016), p. 67

175 Gindner, K. Rajal, M. Zimmermann, P. Tognoni, M. & Geismann , M. (2015)

176 Fancas, D. & Simon, Z. (2011), p. 8

177 Fancas, D. & Simon, Z. (2011), p. 8

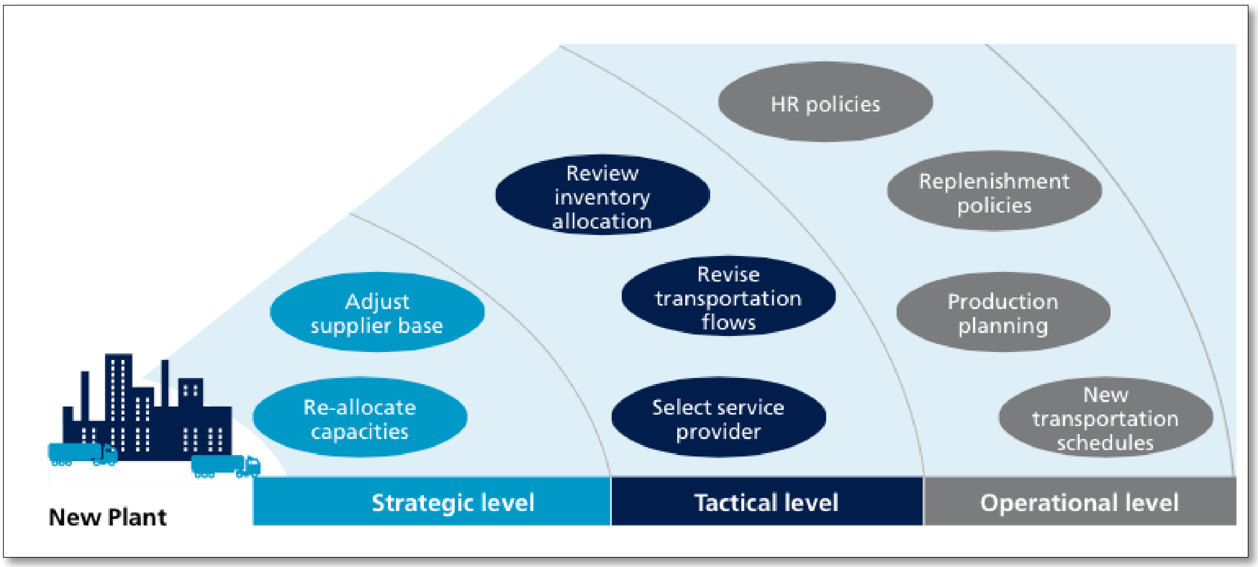

Figure 6.4 Strategic supplier network at various levels[178]

The global manufacturing network requires support from the various supply chain processes for its efficient performance. These supply chain processes can add a tremendous value to building a good supplier network. These processes can be defined as follows:[179]

a. Demand management

b. Production Planning

c. Customer relationship management

d. Distribution

These processes define the supply chain network of a company. A company needs to be well equipped in order to meet the customer demands and thus it has to strengthen its quality and delivery time so that it meets the dynamic customer demands. Subsequently, the flow of information to the production department is vital. The actual volume of production and the schedule determines the stable production plan. This helps when there is a sudden increase or decrease in the volumes. Various means of

[178] Fancas, D. Simon, Z. (2011), p. 8

[179] Diederichs, R. (April, 2016), pp. 69 - 70

distribution help in tackling the longer lead times. These means are by ship, air or land. This is applicable for the inbound as well as outbound logistics process.[180]

All the processes combined lead to a global sourcing strategy. The global sourcing is defined as “the process of integrating and coordinating materials, technologies, processes, designs and suppliers across the global manufacturing and purchasing locations”.[181] The companies approach global sourcing followed by the local and international sourcing. Global sourcing manages many combined activities at a cross-functional level.[182]

All the processes mentioned above can help to attain a successful implementation of a global manufacturing network. An organization should be able to capitalize on the strengths and avoid risks in such events during investing in a global manufacturing site. The country selection is also important so that the process is sustainable and attains profits. Apart from the primary factors, the secondary factors such as languages, cultures, economy and other soft factors help in building a stronger manufacturing footprint. All such factors are very essential in building a world class manufacturing network and a superior supply chain.

[180] Fancas, D. Simon, Z. (2011), p. 8

[181] Monczka, R. & Handefield, R. (2005)

[182] Jiang, C. & Tian, Y. (August, 2009), p. 5

7 Cost modeling

There are different cost estimation techniques used to calculate the cost of the process and the product of an organisation. These techniques have evolved from being simpler to complex cost models. Increased market competition, need for continuous improvement, complexity of the processes and the variety of the products are some of the factors influencing the evolution of the cost modeling techniques. Cost models help to improve and optimise the manufacturing processes and the activities related to the processes.

7.1 Activity based costing

One of the most widely used techniques for cost modeling is the activity based costing. It is an approach of calculating the costs of the product or the process of an organisation on the basis of the activities performed during the manufacturing process.[183] Most of the OEMs follow such an approach for cost modeling. The model consists of identification of the important activities performed during the manufacturing process. This approach is preferred over the traditional costing approach where the cost allocation is according to the labor, raw materials and the overhead costs.[184] There are various steps implemented in the activity based costing. These can be discussed as follows:

a. Identification of the activities

Every manufacturing process consists of many activities, which are performed to produce a product. The management needs to identify these activities so that the resources are assigned to the activities. It is very important to list out the activities so that the detail costs can be calculated for the corresponding activities.[185]

b. Assigning resource costs to the activities

The resources are being utilised by the activities. The consumption of the resources leads to costs. The resources are considered as the labor, materials, equipment, and

[183] Jurek, P. (January, 2012)

[184] Monteiro, A. (September, 2001)

[185] Edwards, S. (November, 2008), p. 5

the infrastructure needed for the activities. These resource costs can be divided into three parts such as the direct costs, indirect costs and the administration costs.[186]

c. Identification of the outputs

The outputs in a manufacturing process are the products. These are also called as the cost objects. It is important to identify all the outputs for which the activities are performed and the resources are consumed. The outputs can also be termed as services and customers.[187]

d. Assigning activity costs to the outputs

In activity based costing approach, the activities are related to the outputs for more accurate cost distribution. With the help of the activity drivers, the costs are related to the outputs. These drivers are related to the causes of the consumption by the outputs.[188] The costs are therefore traced accurately and provide a good overview of the costs of the total system. All these steps are followed to implement the activity based costing and also allows distributing the overhead costs accurately.[189]

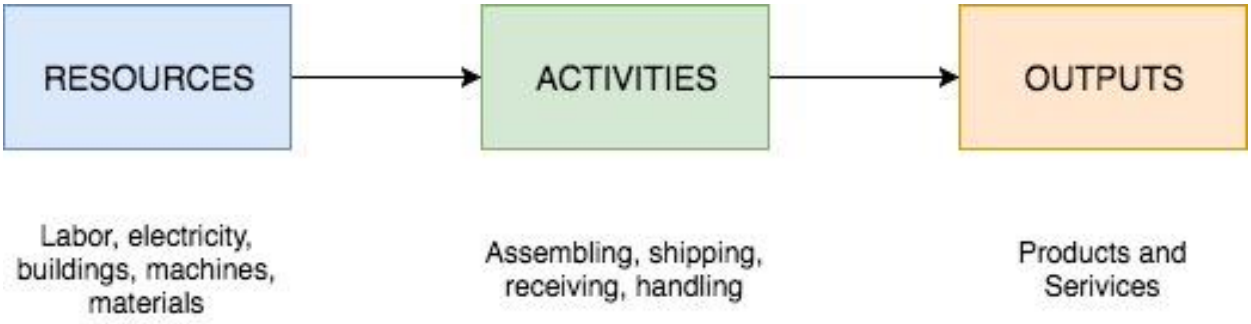

Figure 7.1 Activity Based costing distribution chain

The activity based costing approach identifies many activities, which add value to the product. This helps the managers to identify and eliminate the waste during the manufacturing process.[190] The activity based costing also supports the process of

186 Edwards, S. (November, 2008), p. 6

187 Edwards, S. (November, 2008), p. 6

188 Jurek, P. (January, 2012), p. 2

189 Jurek, P. (January, 2012), p. 2

190 Turney, P. (1989)

continuous improvement through identification of the activities. It also improves the quality and the efficiency of the manufacturing process.

There are other cost accounting techniques as well, which are used, in the manufacturing industry. These accounting techniques are not as beneficial as the activity based costing. Some of the traditional cost accounting techniques include standard costing, marginal costing, and absorption costing. These are not followed today due to their incapability of finding out relevant results. On the other hand, the modern techniques include target costing, life cycle costing, throughput costing, and back flush costing.[191]

a. Standard Costing

The standard costing approach is followed by the organisations, which include repetitive activities in their manufacturing process.[192] This technique compares the actual cost with the planned standard cost of a product. A standard is being set for each of the manufacturing operations. The actual performance is then compared with the standard performance. The variances are reported from the actual and the standard performance. One of the approaches followed in the standard costing is the historical data, which is used to set the standard costs. These data are used to calculate the labor hours and the material requirement for a process. As this approach is highly reliable on the previous data, it cannot be used for the manufacturing industries with different set of activities.[193]

b. Marginal costing

Presentation of the cost values separately as the variable costs and the fixed costs is done in the marginal costing approach. It is used to calculate the cost of the extra units of the product produced in the manufacturing process. This technique is generally used for short term decisions such as make or buy decisions, accepting an order, and outsourcing decisions.[194]

c. Absorption costing

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[191] Tabitha, N. & Ogungbade, O. (February, 2016)

[192] Edwards, S. (November, 2008)

[193] Tabitha, N. & Ogungbade, O. (February, 2016), p. 50

[194] Tabitha, N. & Ogungbade, O. (February, 2016), p. 52

Absorption costing is also known as full costing technique where all the costs are considered as the product costs. It is a useful technique for determination of the product costs as all the costs are covered in this approach. It consists of both the fixed and variable costs.[195]

d. Target costing

Target costing is a technique where the product cost is calculated with the help of a predetermined target cost. It involves setting of a target cost even before the manufacturing of the product. This target cost is then achieved by subtracting the profit desired by the organisation. It helps the organisation to achieve higher profits. Such a technique is useful in the service industries rather than the manufacturing industry.[196]

e. Life cycle costing

Life cycle costing identifies the total cost of ownership of an asset including the costs of operation, maintenance. It covers all the costs of equipment or a project throughout its life cycle. Life cycle costs are useful in improving awareness of the management about the consequences of the decisions, improving forecasting, and minimizing the project costs.[197]

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[195] Tabitha, N. & Ogungbade, O. (February, 2016), p. 51

[196] Fliegner, W. (July, 2015)

[197] Barringer, P. (May, 2003)

8 Best cost country sourcing

The master thesis focuses on a best-cost country sourcing approach for the battery packs of a battery electric vehicle. Today such an approach is valuable to achieve lower costs, which in turn affects the total cost of the product. Globalization has pushed the companies to initiate the sourcing activities from the developing nations. It has improved the trade regulations and tariffs thereby reducing the risks to invest in the developing countries.[198] These advantages have made the best-cost country approach more suitable for the companies. The best-cost country sourcing also gives the companies an edge to make their footprint in the corresponding locations.[199] However, the approach has its own advantages as well as disadvantages.

8.1 Advantages of best-cost country sourcing

As discussed in the earlier section, the best-cost country sourcing has a lot of advantages to offer. These advantages help the companies to build a superior supply chain network. The advantages can be listed down as follows:[200]

a. Best-cost country sourcing helps the companies to establish themselves in the areas of a developing economy.

b. Reduced costs help to attain higher economies of scale.

c. Access to new technology, market, and opportunities. Sourcing from other countries can help to get better service and products due to the high investments.

d. Raw material and the labor costs are cheaper. This is one of the important highlights of the best-cost country sourcing. Many companies move towards the developing nations in order to get the cheaper labor access.

e. The companies can benefit from the competitive edge over the other competitors by best-cost country sourcing.

[198] GEP. (2013)

[199] Eriksson, H. & Lerenius, J. (2004), p. 9

[200] Dutzler, H. et. al. (2011)

8.2 Potential risks of best-cost country sourcing

Besides the advantages of the best-cost country sourcing, there are many risks in encountering this approach. The factors that can cause problems are cultural differences, logistics, lack of research and development, skilled labor and regulations in trade.[201] It can also cause the disclosure of the important information, which can cause serious problems for the organisation. This can cause the downfall of the company and weaken the market share. International logistics also needs to be taken care of as the different locations can cause complexity. The potential risks can overshadow the advantages in terms of cost savings. Hence it is necessary to tackle the risks so that the companies can benefit from the advantages. Some of the risks, which can be encountered while best-cost country sourcing, are as follows:[202]

a. A political instability at a certain location can cause disturbances in sourcing. There is a risk in the successful implementation of such a practice from these regions.

b. Different regions can include many types of different costs. There is a risk of having trade regulations and other such obstacles. The geographical factors can also hamper the logistics network in the supply chain.

c. Quality can be one issue, as the developing regions might not have access to the high technological equipment.

d. The sharing of the data can also be seen as one of the risks. The sharing of intellectual property can cause many problems for the company and can result in losing the market position.

[201] Jiang, C. & Tian, Y. (August, 2009), pp. 14-15

[202] Min, H. (July, 2011)

9 Value chain and strategies for BEV manufacturing

The main aim of the master thesis is to study the supply chain network of the battery electric vehicle manufacturing. It also includes the cost model for the battery pack manufacturing through best-cost country sourcing. The cost model involves regions where the battery pack can be manufactured. It constitutes the types of cost, which are associated with the model and help in calculating the total cost of the battery pack. As discussed earlier, there is a considerable amount of difference between the supply chain strategies of conventional vehicle manufacturing with respect to the electric vehicles. These strategies will be discussed in this section of the report. Moreover, how the best-cost country sourcing affects the costs of the battery pack will also be evaluated in the report.

This chapter specifically deals with the empirical study of the master thesis. It illustrates the methodology used in order to find the results to the research questions. The research methodology consists of quantitative as well as qualitative analysis. It also affects the conclusions drawn after the research work. The gathering of the data, information through interviews and basis for the theoretical framework through the journals and articles are some of the ways of analysis. The master thesis consists all the required data to achieve better and conclusive results.

The basis for the empirical study has been discussed in the earlier chapters. The theoretical framework forms a solid base to put forward the practical implications and solutions. However, the empirical data completes both the aspects of the master thesis with conclusive solutions and further opportunities. However, there are also many constraints, which have been discussed ahead in the report.

9.1 Supply chain for battery electric vehicle manufacturing

The supply chain network for battery electric vehicle manufacturing consists of different supplier networks as compared to the conventional vehicle manufacturing. These are mainly differentiated by the powertrain technologies.[203] In the case of a purpose car model, the entire supply chain can be different. The main players in the electric car manufacturing industry are the battery pack manufacturers, suppliers for motors, power

[203] Ernst, C. et. al (November 2012)

electronics and controllers, and the tier 3 suppliers such as battery pack raw material manufacturers. This has drastically changed the entire supply chain, which can be seen in the figure below. Figure 9.1 shows the supply chain network across the electric vehicle manufacturing.

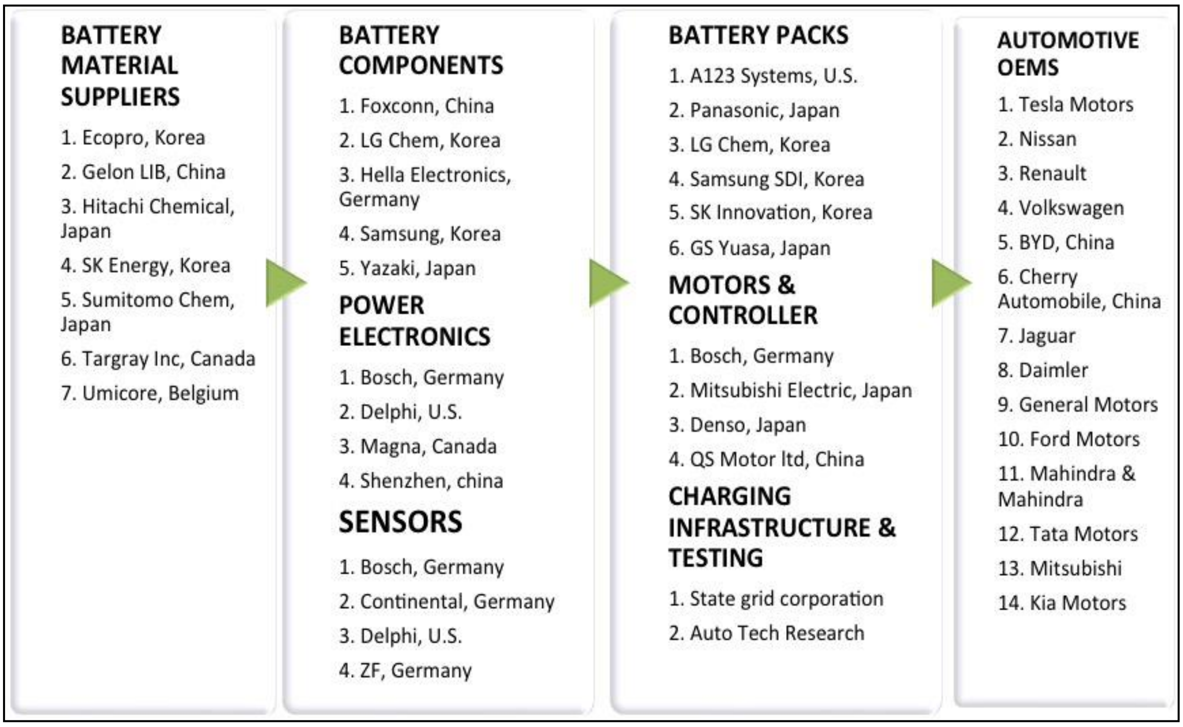

Figure 9.1 Supplier network for electric vehicle manufacturing[204]

The above figure depicts the companies associated with the supplier network right from the raw material supply to the OEMs. This consists of the network of the tier 3 suppliers to the OEMs. It can also be seen that the network has been transformed as compared to the conventional vehicle manufacturing. However, the suppliers in the picture are based on the differentiation of the powertrain technologies.

9.1.1 Implications on supply chain for BEV manufacturing

The nature of supply chain and logistics across the manufacturing network has changed due to the shift in the electric car manufacturing. The manufacturing of electric vehicles has huge implications on the entire supply chain network. This also has effects on the

[204] Lowe, M. et. al (October, 2010), p. 34

inbound, in-house and outbound processes in the manufacturing area for the electric vehicles.[205] These effects will be discussed in the further part of this section.

The inbound supply chain is the area where the supply chain has changed dramatically. As discussed earlier, the electric vehicles are differentiated with respect to its powertrain. Hence, the powertrain components in the conventional vehicles are replaced by the components such as battery packs, controllers, power electronics, and motor.[206] This helps to create new suppliers in the electric vehicle manufacturing industry. On the other hand, the existing suppliers might face difficulties and lose the market to the new electric drive suppliers. The OEMs might lose the value addition of the components such as engines and gearboxes.[207]

The OEMs have to, therefore, think if the value addition needs to be done in-house or create and develop a supplier with a respective expertise in the components. The transformation to the electric car manufacturing has diverted the focus on many essential components such as battery packs and electric motors. This, in turn, has changed the core competencies of the automobile manufacturers. They have to now build upon their new competencies and adapt accordingly in order to be successful in the electric car segment.[208] This leads to various forms of supply chain strategies. The new suppliers are also looking to make the most of the new possibilities in order to enter the automotive segment. This has increased the challenges for the OEMs who are new to electric car technology and the emerging suppliers who want to penetrate in the electric car segment.[209]

The changes in the value chain are experienced right from the supply of the raw materials to the mobility services in the electric car manufacturing. The new concepts will require the inception of new ideas and components. The need of new components automatically triggers the supply of different raw materials. At the end of the value chain, it can also be seen that in order to succeed with the new idea of electric vehicles,

[205] Klug, F. (2013), p. 2

[206] Valentine-Urbschat, & M. Bernhart, W. (2009), p. 8

[207] Valentine-Urbschat, & M. Bernhart, W. (2009), pp. 6 - 8

[208] Klug, F. (2013), p. 3

[209] Klug, F. (2013), p. 3

the companies need to have a good business model.[210] These all aspects have been depicted in figure 9.2.

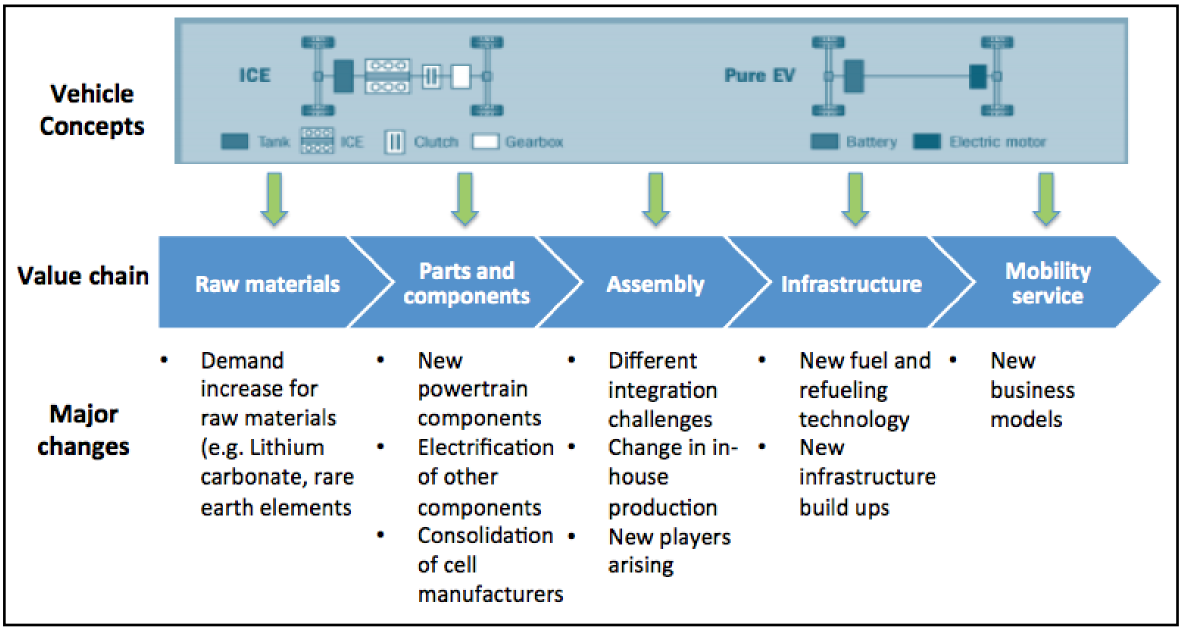

Figure 9.2 Change in the value chain for electric vehicle manufacturing[211]

The figure illustrates the changes in the value chain for electric vehicle manufacturing as compared to the traditional vehicle manufacturing. These changes affect the entire mobility value chain with the opportunities as well as risks in some areas. The value chain is segmented in parts like raw materials; parts and components used especially in the powertrain, integration and the assembly of the vehicles, infrastructure and charging options and the mobility service providers.[212]

The electric car manufacturing requires a different set of raw materials especially for the batteries and electric motor. The advantages of the use of Li - ion batteries were discussed in the earlier chapter. As a result, the suppliers concentrate on the use of lithium-ion batteries as a source of electricity for the electric vehicles. The lithium-ion batteries involve manufacturing of cells where the raw materials are being used. The raw materials constitute composition of several other materials alongside lithium. Thus the demand for lithium has increased considerably high as earlier. This has also lead to the increase in the price of lithium and other raw materials. The battery cells consist of

[210] Valentine-Urbschat, M. Bernhart, W. (2009), p. 70

[211] Valentine-Urbschat, M. Bernhart, W. (2009), p. 70

[212] Valentine-Urbschat, M. Bernhart, W. (2009), p. 71

an anode and cathode, which has several compositions of other materials. The main focus of the chemical industry is on the cathode materials, which also requires lithium. In this area, the issue of patents can be complex in the coming years. The chemical industry suppliers are also looking forward to keeping a hold on the expertise and the research to be competitive.[213]

Besides, the lithium ion battery other parts such as power electronics, AC/DC converters, DC/DC converters, electric motors and auxiliary components are also introduced in the automotive industry. These components will definitely see an increase in demand with the electrification of the powertrain. The introduction of these components will benefit the new supplier industry and help make a larger impact on the automotive industry.

The change in the supply network is also evident at the end of the value chain. The source of fuel has been changed to electric energy with respect to the electric vehicles. This has increased the infrastructure for the refueling and other new fuel sources. These infrastructure facilities are controlled by most of the state-owned grid corporations and also the private owners. This has also helped to an open competition amongst the regional as well as international players.[214]

Another change in the value chain is the entrance of the new business models. The high pricing of the lithium ion battery has made a way for battery leasing business models. These models have seemed to be popular and on an increasing side. The customer mobility service will also help to improve the electric mobility in the near future.[215]

9.2 Alliance strategies in the supply chain

The OEMs consider powertrain as one of their core competencies.[216] They try to form various strategic alliances with the potential suppliers especially for an important component such as the battery pack. Also, there are various strategies to establish a

[213] Valentine-Urbschat, M. Bernhart, W. (2009), pp. 71 - 72

[214] Valentine-Urbschat, M. Bernhart, W. (2009), p. 72

[215] Valentine-Urbschat, M. Bernhart, W. (2009), p. 79

[216] Ernst, C. et. al (November, 2012), pp. 3 - 4

strong supply chain network with the suppliers. On the other hand, the suppliers try to build and secure their own competence as in the case of battery packs.[217]

There are possibilities of two scenarios for a strategic alliance for the electric vehicle manufacturing. These alliances have their own advantages as well as disadvantages both for the OEMs and the suppliers. One of the alliance strategies is the collaboration between the OEMs and the cell manufacturers.[218] With the increasing demands for the electric vehicles and new technologies, OEMs have teamed up with some of the leading lithium-ion cell manufacturers. One such example of such an alliance strategy is Tesla – Panasonic alliance. Tesla Motors, USA has teamed up with one of the leading battery cell manufacturers, Panasonic for the electric vehicle battery technology. Panasonic deals with the manufacturing of the cylindrical lithium ion cells for the Tesla car's battery packs.[219]

The alliance strategy in which the OEM teams up with the cell manufacturers gives the OEM many benefits such as technological advances in the cell manufacturing, the capacity of the cell manufacturer and the edge in the technology used. It provides the OEMs the chance to stand out themselves in the desired battery technology. However, such an alliance strategy has its own disadvantages as well. OEMs need to be well ahead in terms of the technology used. They also need to keep an eye on the competitor's technology, which can overtake the OEM. In such a case, OEMs get less amount of time to react to the technological progress made by the competitors.[220] Figure 9.3 depicts the alliance strategy of such a kind.

[217] Klug, F. (2013), pp. 2 - 3

[218] Dinger, A. Martin, R. Mosquet, X. Rabl, M. Rizoulis, D. Russo, M. & Sticher, G. (2010), p. 10

[219] Dinger, A. et.al. (2010), p. 10

[220] Dinger, A. et.al. (2010), pp. 11 - 12

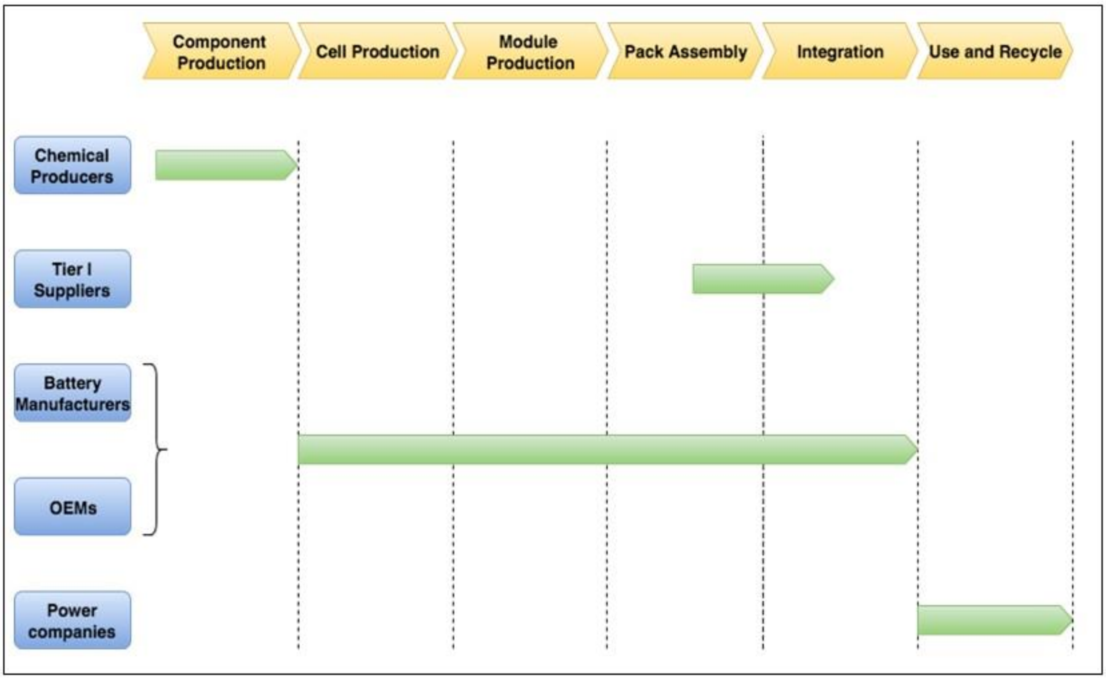

Figure 9.3 OEM alliance with the Battery cell manufacturers[221]

The figure illustrates the key players associated with the value chain network for the manufacturing of a battery pack for electric vehicles. The main alliance formed is between the OEMs and the battery manufacturers. Tier 1 suppliers are also closely associated with the battery manufacturers and the chemical producers are the next tier of the suppliers. This is one of the common strategies being employed now a day to become successful in the segment of electric vehicle manufacturing. The results obtained from the Tesla – Panasonic alliance favors such a type of an alliance strategy.[222]

The other type of strategy is the alliance of the tier 1 suppliers with the battery manufacturers.[223] This strategy has also been implemented for the electric vehicle manufacturing. One such example is the joint venture between Bosch and Samsung Batteries known as SB LiMotive. In such a type of alliance, the tier 1 suppliers help the battery manufacturers to get an access to the OEMs easily. The prior relationships of the tier 1 suppliers with the OEMs make it easy to build relations. In such a strategy,

[221] Dinger, A. et.al. (2010) pp. 10 - 11

[222] Dinger, A. et.al. (2010), pp. 10 - 11

[223] Dinger, A. et.al. (2010), p. 11

the OEMs get less detailed information about the technology used. They also don't have much of a control of the technology used in the battery packs and other components. On the hand, the strategy helps the OEMs to easily switch to another supplier in case of adopting a new technology. This further reduces the costs and allows flexibility. A diagrammatic representation helps to better understand the difference between the two strategies.[224]

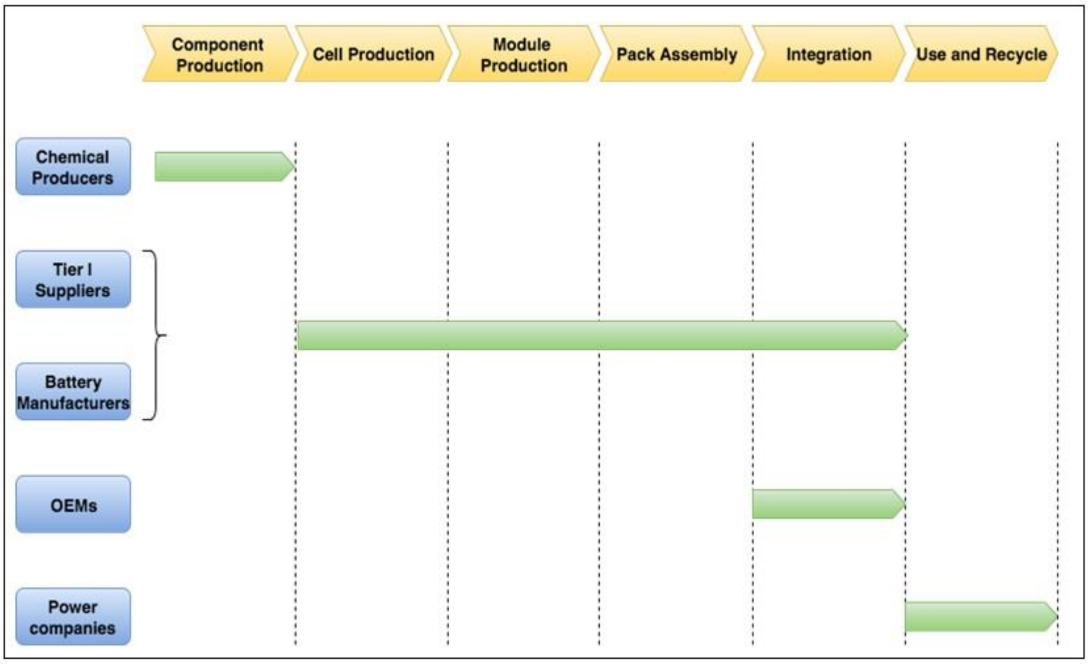

Figure 9.4 Alliance between tier 1 suppliers and battery manufacturers

Both these strategies have been implemented for the electric vehicle manufacturing. However, the strategic alliance between the OEMs and the cell manufacturers prove to be more beneficial for the OEMs. This helps them to have the competencies in-house and develop the further technology. There can also be several other ways to integrate the functions, which can affect the value chain in the electric vehicle manufacturing. These types of possibilities can be listed down as follows:[225]

a. Battery manufacturing company and an OEM forming a single manufacturing company.

[224] Dinger, A. et.al. (2010), pp. 10 - 11

[225] Klug, F. (2013), pp. 1 - 3

b. Acquisition of a battery manufacturing company by an OEM.

c. Battery manufacturing company expanding into an electric vehicle manufacturing company.

d. Cooperation of OEMs and the suppliers for the parts and components

These are the likely scenarios when forming an alliance strategy for the electric vehicle manufacturing. A considerable amount of impact can be noticed on the entire supply chain with the help of such alliances. It is an open-end discussion to choose a particular strategy. However, the OEMs seem to benefit to a greater extent with the help of both the strategies discussed in this section.[226]

9.3 Value add analysis for the powertrain components

In order to be competitive, the OEMs need to ensure that the products add value. The powertrain is a component, which differentiates the electric vehicles from the conventional vehicles. The shift to the electric vehicles has introduced many new components such as motor, battery pack, converter and power electronics. In this section, the value added by these components to the product is compared with that of the powertrain components for an internal combustion engine. This gives a detailed view of the value contribution of the components to the powertrain. The following diagrammatic representation shows the exact distribution of the value added to the components.[227]

[226] Klug, F. (2013), pp. 1 - 3

[227] Ernst, C. et. al (November, 2012), p 5

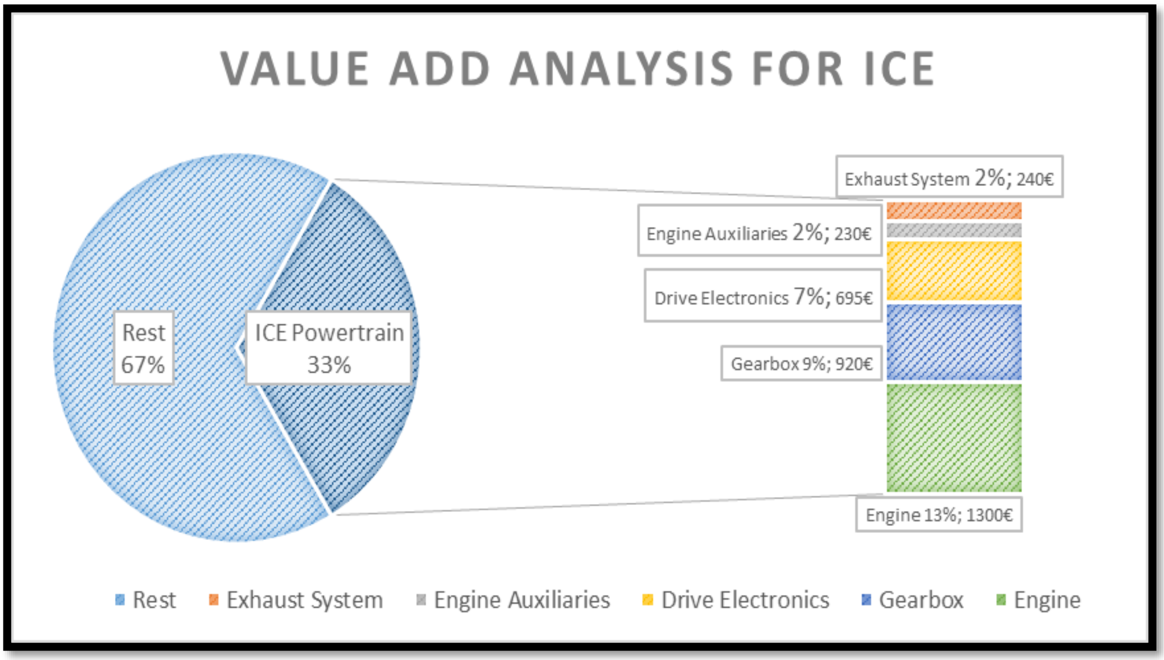

Figure 9.5 Value add analysis for ICE vehicle[228]

The figure 9.5 depicts the value add analysis for the traditional vehicle. It shows that only 33% of the total value is being added by the powertrain components. Out of the given 33%, the engine and the gearbox generate most of the value. It implies that these components constitute an important part of the value generation. Therefore, the OEMs also tend to focus on these components and generally keep this competence in-house. The remaining powertrain components such as drive electronics, exhaust system and engine auxiliaries contribute comparatively very less amount of value to the whole vehicle. The OEMs therefore outsource such components from the suppliers. These components are the main stay of the supplier groups.[229]

The value-add analysis provides the OEMs an idea to focus on a particular component with the high amount of value contribution. This helps OEMs to strategize, which parts should be produced in-house and which should be outsourced from the suppliers. Such an analysis helps to place the products in the portfolio according to the competence. It also makes the make or buy decisions easier for the automobile manufacturers.[230]

[228] Ernst, C. et. al (November, 2012), pp. 4 - 5

[229] Ernst, C. et. al (November, 2012), pp. 4 - 5

[230] Ernst, C. et. al (November, 2012), pp. 5

The second value-add analysis comprises the components of the battery electric vehicle. The contribution of the BEV components can be shown in the figure 9.6

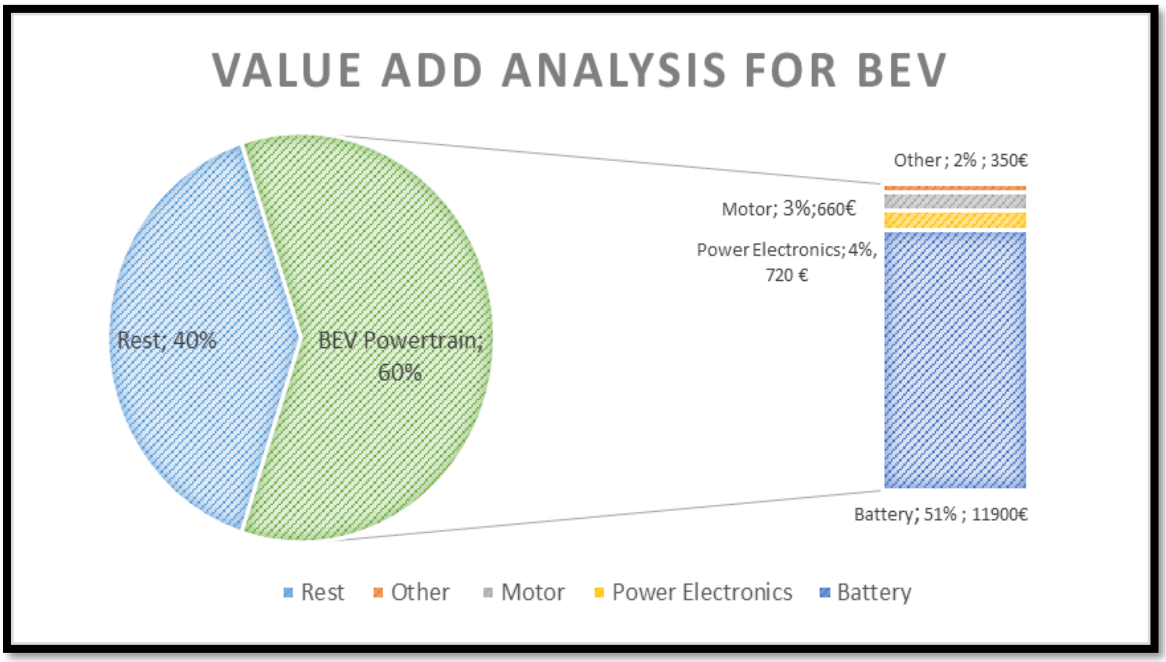

Figure 9.6 Value add analysis for BEV[231]

The figure is a representation of the value added by the battery electric vehicle components to the product. As compared to the internal combustion engine vehicle, the powertrain of the electric vehicles contribute 60% of the value to the product. This is far more than the conventional vehicle powertrain. Furthermore, the main component of the entire powertrain is by far the battery pack, which alone contributes 85% of the total powertrain value. Hence the OEMs look forward to keep the competence strength in the battery pack with them and outsource the other components. The outsourced components consist of power electronics, motor, and other auxiliary parts. In this case, these components are the mainstay of the suppliers.[232]

The value-add analysis thus shows that the battery pack is one of the essential components of the powertrain, which provides maximum value to the product. The master thesis thus focuses deeper on the battery pack costs ahead in the report. The main reason for selecting the battery pack was the value added by the component to the whole vehicle. Also, the exact cost proportions of the complete battery pack

[231] Ernst, C. et. al (November, 2012), pp. 5 - 6

[232] Ernst, C. et. al (November, 2012), pp. 5 - 6

components, which helps to understand the cost structure better has also been discussed further in the report. Modeling such costs consists of manufacturing cost of battery packs in the best-cost countries.

10 Cost modeling of battery pack manufacturing

The value-add analysis proves that the most valuable component of the battery electric vehicle is the battery pack. Hence, one of the focuses of master thesis is on the manufacturing cost of the battery pack, which will be discussed in detail in this chapter. The cost model deals with the manufacturing cost of the lithium-ion battery pack used in the battery electric vehicle. It takes into account the parameters such as specific power, energy and the number of cells in the battery pack. Every step of the battery manufacturing process is considered for the calculations. The costs includes material costs, variable costs, fixed costs, installation costs of the equipment, labor costs, and landed costs.

The master thesis was done at AVL List GmbH, Austria. The main purpose of the cost model is to observe the exact cost breakdowns of the lithium ion battery packs. It aims to find out the deviation in the cost of the battery pack manufactured in different locations. Therefore, the approach of best-cost country sourcing is considered. The cost differs in many aspects with respect to the different manufacturing locations. Another aim of the cost modeling is to improve the existing ways of manufacturing cost calculations and compare it with the earlier methods at AVL List GmbH.

The cost model is based on a research model, which helps to identify the battery performance and costs for a battery pack used in the electric vehicles. This cost model is known as the BatPaC Model, which was developed at the Argonne national laboratory, U.S.[233] Some of the costs are being scaled up from the BatPaC model and are used as a reference. The basic battery design parameters and design calculations are also referred from the same model. The model has helped to find various ways and solutions for calculating the battery pack manufacturing costs. ProCalc, software used at AVL GmbH List is also used as a reference for cost calculations. The software is used to calculate mainly the manufacturing costs and other costs related to the manufacturing process.[234]

[233] Nelson, P. Gallagher, K.G. Bloom, I. & Dees, D.W. (December, 2012), p. 1

[234] AVL List GmbH, Internal Data

10.1 Best cost country sourcing for battery packs

The higher costs of the battery packs in the electric vehicles have substantially increased the total cost of the car. Therefore, the selection of best-cost countries for the manufacturing of the battery packs is considered. This can help to know the respective market better and also reduce the costs by a higher margin. Figure 10.1 shows the best locations for a global manufacturing footprint.

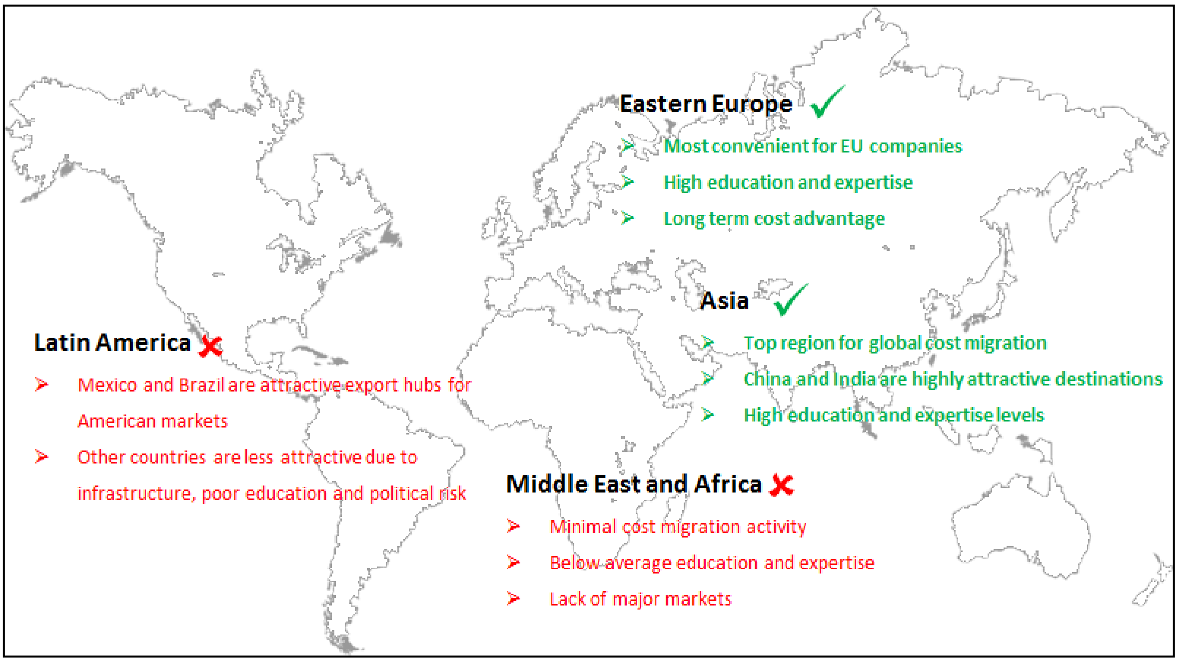

Figure 10.1 Manufacturing sites for global outsourcing[235]

According to the figure, the best locations for a global manufacturing footprint through the best-cost country sourcing are the regions of Asia and East Europe. These regions offer many advantages as compared to the other regions. Today, every automobile company has its manufacturing footprints in these regions. For the cost modeling of the battery pack manufacturing, these regions were found appropriate and three countries were selected for the analysis. These countries have several advantages especially in the field of electric vehicle manufacturing and its related processes. The cost of battery pack is calculated for the regions like China, India, and Slovakia.[236]

[235] Vestring, T. Rouse, T. Reinert, U. & Varma, S. (2005), p. 6

[236] Vestring, T. Rouse, T. Reinert, U. & Varma, S. (2005), pp. 5 - 6

10.1.1 China

The main reason for using these locations is the availability of raw materials, proximity to the OEMs, high education levels and low labor costs. China has been a leader in the electric vehicle manufacturing. The availability of cheap raw materials favors the manufacturing of the battery packs in China. Moreover, the labor costs also prove to be an advantage for the battery pack manufacturing in China. It also has the required infrastructure, which proves to be a major advantage.

10.1.2 India

India is also one of the favored sites for a global manufacturing network. The labor costs are much less than compared to China and it also has higher education level. India has been pushing for the use of electric vehicles and is seen as one of the emerging markets for the electric vehicles.

10.1.3 Slovakia

Slovakia is also regarded as one of preferred locations in Eastern Europe for manufacturing. With respect to the electric vehicles, the government provides much higher subsidies for the purchase of electric vehicles.[237] The cost of labor and relatively low custom duties in the eastern European region favors the battery pack manufacturing in this region. The rapid charging infrastructure has also been developed across the country, which has improved the charging network.[238]

10.2 Benchmarking for battery cells and battery pack

The battery cells and the battery pack require a standard design for the calculation of its manufacturing cost. Hence, the design parameters are benchmarked with respect to another battery pack used in the electric vehicles. The battery pack used for benchmarking is from the car model Renault ZOE (ZE 40 Battery). The cell structure and the battery pack structure are also being benchmarked. This consists of number of cells, raw materials used for the cells, specific power and energy. This helps to get a standard format of the required battery pack, which is helpful for the cost calculations.

[237]https://cleantechnica.com/2016/11/16/slovakia-ev-subsidies-approved-e5000-zevs-e3000-phevs/

[238]https://transportevolved.com/2014/05/14/slovakia-welcomes-electric-cars-rapid-charging-west-east-trek/

The Renault ZOE battery pack is regarded one of the most technically advanced battery packs.[239] The diagrammatic representation of the Renault ZOE battery pack is shown in figure 10.2.

Figure 10.2 Renault ZOE battery pack[240]

10.2.1 Cell chemistry

There are many numbers of chemistries possible in case of the lithium ion battery. The combination of the anode and cathode materials has various advantages and disadvantages.[241] The types of cell chemistries used in the lithium ion battery are lithium-nickel-cobalt-aluminum (NCA), lithium-nickel-manganese- cobalt (NMC), lithium-manganese spinel (LMO), lithium titanate (LTO), and lithium-iron phosphate (LFP). These materials are called as the active materials, which are held together by the polymeric binder.[242] These chemistries are based on parameters such as safety, cost, specific power, lifespan, and performance. It is difficult for a single cell chemistry to fulfill all the requirements but a balance of all the parameters makes a good choice for the cell manufacturers and suppliers. The cell chemistry for the Renault ZOE is the Lithium-

[239] AVL List GmbH, Internal Data

[240] http://www.worldautoevolution.com/2016-renault-zoe-ev-review-400-km-range/

[241] Dinger, A. Martin, R. Mosquet, X. Rabl, M. Rizoulis, D. Russo, M. Sticher, G. (2012), p. 1

[242] Nelson, P. et. al. (December, 2012), p. 4

nickel-manganese-cobalt (NMC). Comparison of all the required parameters for the cell chemistry is shown in the following diagram.

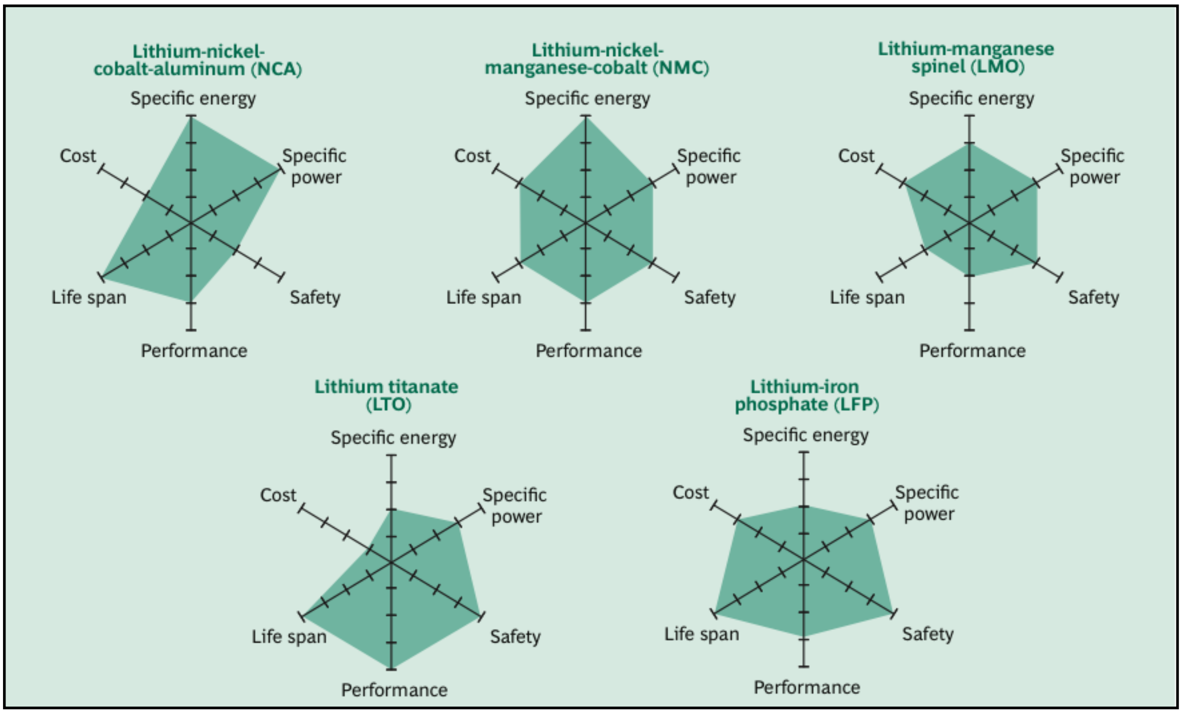

Figure 10.3 Lithium-ion battery cell chemistries[243]

Figure 10.3 suggests that the Lithium-nickel-manganese-cobalt (NMC) forms an overall good balance in terms of all the required parameters. Therefore, the cell chemistry selected for the battery cells is considered to be NMC. The anode material for the composition is graphite while the cathode material consists of NMC-622.

Cell chemistry forms an important part to calculate the specific energy and power of the total battery pack. However, the research laboratories are developing new cell chemistries, which will provide better performance in the near future. The main challenge is the higher costs and achieving higher economies of scale can compensate this. In the case of the master thesis, the detailed cell chemistry has been formulated. The other raw materials included are electrolytes, solvents, positive current collectors, negative current collectors, and separators. The details of the raw materials have been formulated in a tabular form.

[243] Dinger, A. Martin, R. Mosquet, X. Rabl, M. Rizoulis, D. Russo, M. Sticher, G., "Batteries for Electric Cars", Boston Consulting Group p 3

Positive Electrode	
Active material capacity, mAh/g (NMC 622)	180
Weight %	
Active Material	89
Carbon	6
Binder	5
Density, g/cm^3	
Active Material	4.65
Carbon	1.825
Binder	1.77
Negative Electrode	
Active material capacity, mAh/g	360
Weight %	
Active Material	95
Binder	5
Density, g/cm^3	
Active Material	2.24
Carbon	1.95
Binder	1.10

Table 10.1 Cell chemistry for positive and negative electrode[244]

[244] Nelson, P. et. al. (December, 2015)

Table 10.2 depicts the cell chemistry for the positive and the negative electrode. Besides this, the raw materials such as electrolyte, separator, positive current collector foil, and negative current collector foil also form an important composition in the cell chemistry. The details for these materials are discussed below in the table.

Positive current collector	Aluminium
Thickness, µm	15
Negative current collector	Copper
Thickness, µm	10
Separator	Polypropylene (PP)
Thickness, µm	15
Electrolyte	Lithium hexafluorophosphate $LiPF_6$
Density, g/cm^3	1.20

Table 10.2 Raw materials for lithium battery cells[245]

10.2.2 Baseline manufacturing plant and boundary conditions

The baseline manufacturing plant is a plant with 200 employees, which is used as a reference to calculate the manufacturing parameters for the battery pack.[246] The costs calculated in the master thesis for the battery pack are scaled from the baseline manufacturing plant. The direct labor hours and the capital investment costs are being scaled from the baseline manufacturing plant. It also includes the individual steps required for the battery pack production. With the help of these parameters, costs such as labor costs, raw material costs, launch costs, variable overhead costs, depreciation costs and warranty costs are considered.

The baseline plant consists of manufacturing of 100,000 battery packs per year. The battery pack produced by the baseline plant consists of 60 cells with the capacity of 40Ah for each cell. The total energy of the battery pack is 8.7 kWh and the total power

[245] Nelson, P. et. al. (December, 2015)

[246] Nelson, P. et. al. (December, 2012), p. 53

is 50 kW. The range of the vehicle for such a battery pack is calculated to be 24 miles with 250 Wh/mile.[247] A schematic representation of the baseline manufacturing plant with the manufacturing steps is shown in figure 10.4.

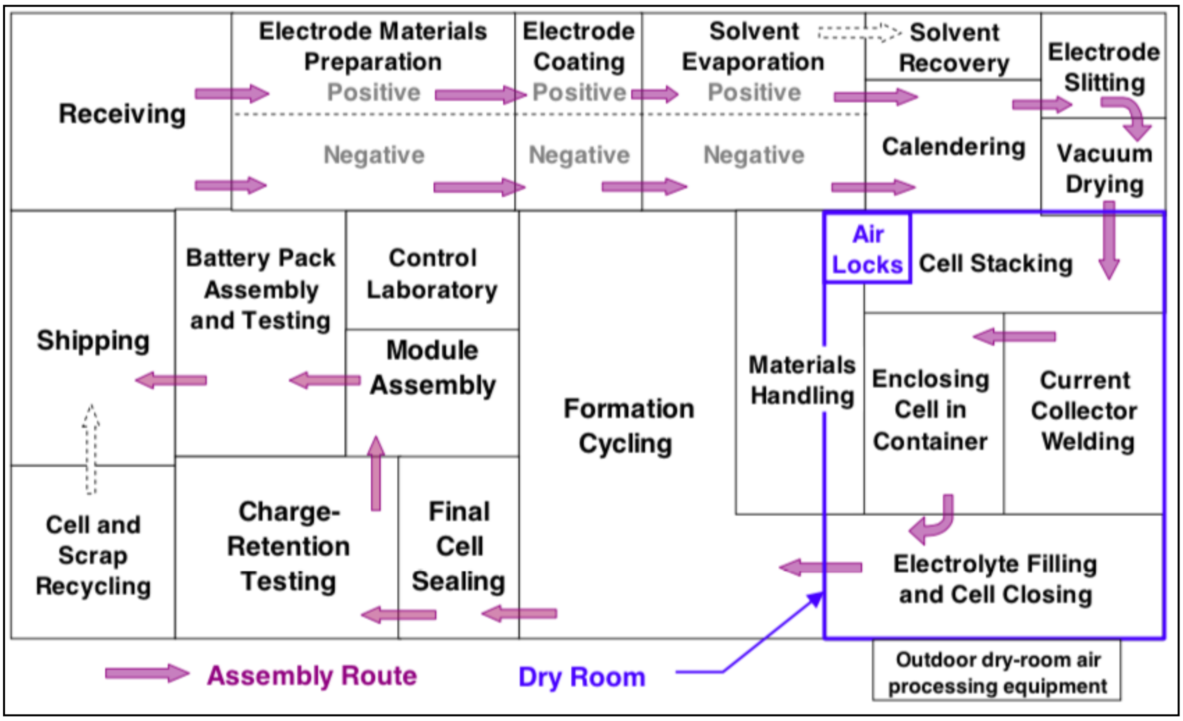

Figure 10.4 Schematic representation of baseline manufacturing plant

The battery pack considered for the master thesis also consists of some boundary conditions. These are the with respect to the battery design, manufacturing locations, battery cell, number of working days for the manufacturing plant, the number of shifts, the total number of battery packs manufactured per year, and other technical specifications. The technical specifications have been benchmarked according to the Renault ZOE battery pack while the manufacturing locations have been selected after a careful consideration of the advantages of best-cost country sourcing. The volume of the battery packs manufactured per year depends upon the sales of electric cars over the years.

247 Nelson, P. et. al. (December, 2012), p. 62

Battery Pack Capacity	40 kWh
No of packs produced	50000
No of working days	300
No of working shifts	3
Battery Type	Lithium ion
Battery system power	80 KW
No of cells per pack	192
Cell Type	Pouch cells
Manufacturing Locations	China, India, Slovakia

Table 10.3 Boundary conditions for battery pack manufacturing

10.2.3 Battery specific parameters

The battery specific parameters are calculated on the basis of the cell chemistry and the boundary conditions. The battery parameters such as electric vehicle range, cell capacity, battery system capacity, nominal voltage for the battery pack, mass, and the volume of the battery pack are calculated. These parameters are also found out on the basis of input parameters such as cell arrangement, the number of cells in the battery system and the desired power. Most of the input parameters are benchmarked with respect to the technical specifications in Renault ZOE. The cell chemistries help to find the exact amount of material required for unit battery pack production.

The battery specific parameters are calculated with the help of various numerical equations and formulae. The list of the formulae and the equations are not covered in the report. The main focus of the cost model is to investigate the manufacturing costs and hence the battery performance equations are not included. However, the battery parameters, which are essential for finding out the manufacturing costs, are covered in the report with its details. These details of the battery parameters are classified in table 10.4.

Battery Parameters	Specifications
Electric vehicle range	167 miles / 268 km
Cell capacity	55.6 Ah
Battery system capacity	111.1 Ah
Nominal battery system voltage	360 V
Battery pack energy requirement	200 Wh/mile
Battery pack mass	235.8 kg
Battery pack volume	136.3 Liters

Table 10.4 Battery specific parameters

10.3 Cost adjustment for production volumes

The varying volumes of production can have a considerable effect on the total cost of the battery pack. The lower cost of the battery packs can be achieved through the economies of scale. Higher the production volume better is a chance to lower the costs per unit of the battery pack. As discussed earlier, scaling up the costs from the baseline manufacturing plant generates the cost for the desired battery pack. Therefore, the costs for the manufacturing of a battery pack with a different capacity and a volume need to be adjusted with the help of a scale factor. This approach is valid to incase of the manufacturing plants with the same product.[248] In order to find a solution for varying volumes of the same product, the known cost from the baseline plant is multiplied by the processing rate raised to the scale factor.[249]

The scaling factor is used to determine the labor hours, capital equipment costs, and the plant area for the manufacturing of the desired battery pack. The general equation, $C = C_0(R/R_0)^p$, is used to find the cost for the desired battery pack with the help of the

[248] Nelson, P. Santini, D. Barnes, J. (May, 2009)

[249] Nelson, P. et. al. (December, 2012), p. 62

known cost values for the baseline manufacturing plant.[250] For instance in calculating the capital equipment cost for the desired plant,

C_0 - Cost of the equipment installed at the baseline manufacturing plant

R – Processing rate or the number of cells manufactured at the desired plant

R_0 – Number of cells manufactured at the baseline plant

p – Scale factor, usually in between 0.1 – 1.0.

The scale factor for calculating the labor hours is usually considered as 0.4 – 0.5.[251] However, some of the steps in the manufacturing process require more labor work and fewer automation levels. In such cases, the scale factor is higher up to 0.8.[252] Even though the production volumes are higher, the cost reduction is less. For calculating the equipment costs, scaling factor increases slightly greater than that for the floor area. When the scale factor, p=1.0, the cost of the equipment tends to be directly proportional to the processing rate. However, the scale factor for the equipment costs is unlikely to be 1.0 as it includes installation of the equipment as well.

There are some cases where additional cost factors have also been included in calculating the equipment costs. The costs for cell stacking and the formation cycling equipment depend upon the capacity of the cell. Hence, the capacity of the cell is also accounted for the cost calculation. Additionally, in the battery assembly process, the equipment cost depends upon the number of cells and the modules for the assembly process. The relationship between the scaling factors and processing rate can be shown in the following table 10.5.

[250] Nelson, P. et. al (May, 2009), p. 6

[251] Nelson, P. et. al. (December, 2012), pp. 71-72

[252] Nelson, P. et. al. (December, 2012), p. 72

$C = C_0(R/R_0)^p$		
	Cost Ratio, C/C_0	
Scale factor, p	$R/R_0 = 2$	$R/R_0 = 3$
0.25	1.19	1.32
0.3	1.23	1.39
0.4	1.32	1.55
0.5	1.41	1.73
0.6	1.52	1.93
0.7	1.62	2.16
0.8	1.74	2.41
0.9	1.93	2.84
1.0	2.0	3.0

Table 10.5 Scale factor for different processing rate[253]

10.4 Cost structure for battery pack manufacturing

The cost structure for battery pack manufacturing is mainly divided into two main cost factors, which are the variable costs and the fixed costs. These are further divided into additional cost factors. The set of the variable costs consists of raw material costs, purchased part costs, labor costs, and variable overhead costs. These are mainly dependent upon the number of the battery packs produced. The fixed costs consist the sales, general and administration costs, depreciation costs, research and development costs, profit and the warranty costs. These are the main types of costs included in the cost model. The costs for the raw materials and purchased parts have been derived from the suppliers of the respective material and parts. The labor costs are the standard

[253] Nelson, P. et. al. (December, 2012), p. 73

costs for the country of manufacturing while the markup for the fixed costs is according to the standards used in the industry.

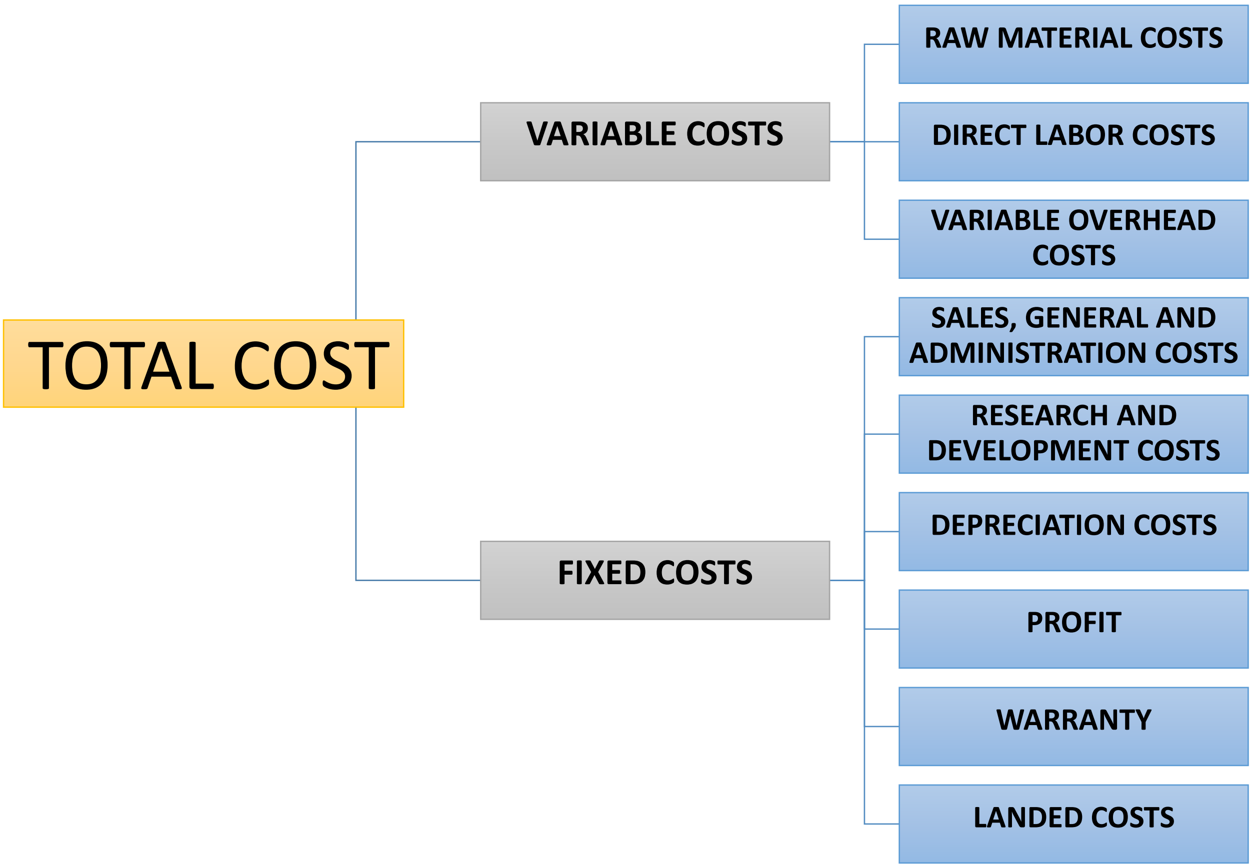

Figure 10.5 Cost structure for battery pack manufacturing[254]

10.5 Investment costs

Besides, the variable and fixed costs involved in the manufacturing of the battery pack, the investment costs are an important factor to be included in cost calculations. These costs are related to the investments in the infrastructure of the manufacturing plant, the starting of the production, installation of the equipment, and the capital required for the functioning of the manufacturing plant.[255] The major part of the costs is the equipment costs and its installation. Table 10.6 shows the different costs related to the investment costs and its method of calculation as well.

The investment costs for the infrastructure depends upon the manufacturing location. The industrial land rates for each of location are taken into account while calculating the

[254] Nelson, P. et. al. (December, 2015) & AVL List GmbH, Internal Data

[255] Chung, D. et al. (April, 2016)

investment costs. The space needed for the manufacturing steps is scaled from the baseline manufacturing plant. The equipment costs are also calculated on the basis of the baseline manufacturing rates. The other costs are the production start up costs, material costs and the inventory costs related to the start of production and the working costs for functioning of the manufacturing plant. The costs for the start of the production are calculated as 5% of the total material costs with 10% of the labor and variable overhead costs.[256] The working capital consists mainly of the work in process inventories, and the material handling costs. These are estimated to be 15% of the total variable costs for manufacturing the product in a year.[257]

Investment Costs	**Description**	**Method of Calculation**
Equipment Costs	Cost of required equipment and its installation	Calculated for each step of manufacturing and scaled up from baseline plant
Land Costs	Costs required for manufacturing space and utilities	Estimated by industrial land costs for China, India and Slovakia for required space
Launch Costs	Production start up costs	5% of material costs plus 10% of total labor and variable overhead costs
Working costs	Costs for the work in process inventory, material handling and logistics	15% of total variable costs

Table 10.6 Investment costs for battery pack manufacturing[258]

10.6 Variable costs

Costs that change with the number of produced quantities are termed as variable costs.[259] These costs mainly consist of raw material costs, purchased item costs, labor

[256] Nelson, P. et. al. (December, 2015)

[257] Nelson, P. et. al. (December, 2012), p. 75

[258] Nelson, P. et. al. (December, 2012), p. 75

costs, and variable overhead costs. The raw material costs, and purchased items costs are categorized as direct costs as these costs are directly related to the product. On the other hand, the variable overhead costs are the indirect costs, which do not influence the costs directly. The variable costs form a major part of the cost model.

The raw material costs for the battery pack manufacturing have been evaluated on the basis of supplier quotations. These costs vary with respect to the location. A major amount of the raw material comes from China and therefore the cost of the material is the lowest for China. The costs for countries like India and Slovakia also includes the taxes and custom duties for each material. The raw material required for the manufacturing of the battery pack will be discussed in detail in the further section. The purchased items are those items, which can be outsourced from other suppliers directly. These are mainly associated with the battery module and pack.

The labor costs also differ from location to location. One of the major aims of the master thesis is the best-cost country sourcing. Hence the labor cost plays an important role in the total cost calculation. These costs are evaluated on the basis of total labor hours required for each manufacturing step. The costs are calculated by the reference of the international labor statistics. However, the labor hours for the manufacturing steps have been scaled from the baseline plant with the help of a scaling factor.

The variable overhead costs are the indirect costs, which are associated with indirect materials, indirect labor, and other utilities.[260] These costs are do not influence the total costs directly. All these types of costs are discussed in detail in the later section of the report.

10.6.1 Raw material and purchased item costs

The raw material and purchased items comprise the most amount of the total costs in the battery pack manufacturing. This section deals with the raw materials and the purchased parts required for the battery pack manufacturing. The material cost is based upon the supplier interactions and quotations while the quantity of the material required annually is calculated on the basis of the material and cell yield. In this section, the raw

[259] Anderson, J. (January, 2009)

[260] Atkinson, A. Kaplan, R. Matsumara, E. & Young, M. (2012)

materials and the purchased parts considered in the cost model and their respective costs are discussed in detail. The cost of the raw materials is received from the supplier, Targray Technology International Inc. The company is one of the leading international suppliers of li-ion battery materials.

a. Positive electrode active material

As discussed in the section 10.2.1, the cell chemistry consists of a positive and negative electrode. The positive electrode chosen for the battery pack manufacturing is NMC 622 due to its advantages over the other materials.[261] China has been one of the leading markets for the raw materials for Li-ion batteries. NMC 622 costs have also been derived with respect to the Chinese markets due to its higher availability and cheaper costs. However, the costs vary for different locations. China being the major supplier has a great advantage over the raw material costs. The cost for NMC 622 for manufacturing in China is estimated to be 20$/kg.[262] The cost for India and Slovakia includes the taxes and custom duties and are calculated accordingly. However, the yield for the positive electrode material is also considered while accounting for the material quantity required for the battery pack manufacturing.

b. Negative electrode active material

Graphite is used as the negative electrode active material for the battery pack manufacturing. There are various other materials, which can be used as anode in the lithium ion batteries. However, graphite is used due to the high energy density at higher voltages, and high capacity.[263] The different types of graphite, which can be used as an anode, are natural, synthetic, and coated-natural graphite.[264] The negative electrode material used for the battery pack manufacturing is natural graphite. The estimated cost for the natural graphite for manufacturing in China, quoted by the supplier is 15$/kg.[265]

c. Electrolyte and separator

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261 Dinger, A. et.al, (2010). p 3

262 “Raw material quotation”, Targray Technology International Inc

263 Muranaka, Y. et al.

264 Nelson, P. et. al. (December, 2012), pp. 56 - 57

265 “Raw material quotation”, Targray Technology International Inc

The function of an electrolyte in the lithium ion batteries is free flow of ions between the electrodes.[266] The electrolyte used for the lithium ion battery pack is Lithium Hexafluorophosphate ($LiPF_6$). The cost of the electrolyte for manufacturing plant in China is estimated at 20$/liter.[267]

Separator is also one of the key elements in the lithium ion battery cells. The separators avoid the electrical short circuits by keeping the positive and negative electrodes apart[268]. There are different types of separators used in the lithium ion batteries. The separator used for the battery pack manufacturing is Polypropylene (PP) with a middle layer of Polyethylene (PE). The availability of these materials is easy, especially in region like China. Hence all such raw materials have been estimated on the base price of Chinese markets. The cost for other locations includes taxes and custom duties for exporting it from China.

d. Current collector foils

The current collector foils used in the battery pack manufacturing are the aluminum and copper foils. The aluminum foils are used for the positive electrode and the copper foils are used for the negative electrode. The cost of the aluminum foil and the copper foil was estimated to be 0.30$/m^2 and 1.30$/m^2 respectively for manufacturing in China.[269]

e. Binder solvent

The binder solvent is also one of the raw materials used in the cell manufacturing process. The binder solvent used for the battery pack manufacturing is N – methyl 2 Pyrrolidone (NMP). The cost estimated is 5$/kg.[270] The binder used is Polyvinylidene fluoride (PVDF) and is priced at 20$/kg.[271]

f. Purchased items

The purchased parts are those parts, which do not require any process to convert into a finished product. These parts have been directly outsourced from the suppliers and are

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[266] Kang, X. (2004)

[267] “Raw material quotation”, Targray Technology International Inc

[268] Arora, P. Zhang, Z. (2004)

[269] “Raw material quotation”, Targray Technology International Inc

[270] “Raw material quotation”, Targray Technology International Inc

[271] “Raw material quotation”, Targray Technology International Inc

especially for the battery cells and battery jacket. These parts have been classified in the table 10.7 with respect to their costs for the manufacturing locations.

PURCHASED PARTS	CHINA	SLOVAKIA	INDIA
Positive terminal, $/kg	3.00	3.15	3.08
Negative terminal, $/kg	5.00	5.25	5.13
Cell container, $/kg	2.00	2.10	2.05
Al. heat conductor, $/kg	3.00	3.15	3.08
SOC regulator, $/cell	2.50	2.63	2.56
Module terminal, $/kg	4.00	5.00	4.50
Module enclosure, $/kg	2.50	3.50	3.00
Battery terminal, $/battery	10.00	15.00	12.50
Battery jacket, $/kg	7.00	8.50	7.50

Table 10.7 Purchased parts for battery pack manufacturing[272]

g. Material yield and costs

During the manufacturing process, the scrap generated needs to be taken into consideration. Therefore, it is considered that 5% of the cells might be scraped in the process of manufacturing. Also, the material yield is taken into consideration. Different material possesses different yield. However, the scrap generated will be recycled and used again in the process. The yield percentage is taken into account for material calculations in the model. Table 10.8 shows the percentage of yields for the cells and different materials.

[272] Nelson, P. et. al. (December, 2012) & “Raw material quotation”, Targray Technology International Inc

MATERIAL	YIELD %
Cell	95.0
Positive electrode	92.2
Negative electrode	92.2
Positive current collector	90.2
Negative current collector	90.2
Electrolyte	94.0
Separator	98.0

Table 10.8 Material yield for battery pack manufacturing[273]

The cost of the raw materials has been stated in the earlier section. In this model, the raw material for India and Slovakia is exported from China. On the basis of various supplier quotations and interactions, China was the most suitable and cheap location for the raw material availability. Therefore, China is considered as an exporter for the raw materials. The availability of the mentioned raw materials in other countries is also not adequate to meet the demands of the manufacturing model. The detailed costs for all the countries are discussed in table 10.9.

[273] Nelson, P. et. al. (December, 2012), p. 71

Unit cell material costs	CHINA	SLOVAKIA	INDIA
Positive Electrode, $/kg			
Active material	20.00	24.00	22.00
Carbon	10.00	12.00	11.00
Binder, PVDF	20.00	24.00	22.00
Binder solvent (NMP)	5.00	6.00	5.50
Negative Electrode, $/kg			
Active material	14.00	16.80	15.40
Carbon	10.00	12.00	11.00
Binder	20.00	24.00	22.00
Al. current collector foil, $/m^2	0.30	0.36	0.33
Cu. current collector foil, $/m^2	1.30	1.56	1.43
Separator, $/kg	1.20	1.38	1.32
Electrolyte, $/L	18.00	21.60	19.80

Table 10.9 Material costs[274]

10.6.2 Labor costs

The labor costs are a part of the variable costs and differ from one location to another location. For the master thesis, the total cost of the battery pack manufacturing is driven mostly by the low labor costs. The labor costs have a drastic effect on the best-cost country sourcing. One of the main aims of the best-cost country sourcing is to achieve lower costs by reducing the labor costs. The countries, which focus on the battery pack manufacturing in this master thesis have lower labor costs.

[274] “Raw material quotation”, Targray Technology International Inc

The labor costs are calculated on the basis of the labor hours for each and every manufacturing step. These labor hours are calculated on the basis of the baseline manufacturing plant. The labor hours are scaled up from the baseline manufacturing plant with the help of the scaling factor. Every manufacturing step has a different scaling factor as it depends upon the amount of labor required for the specific process. The formula for the labor hours calculation is as follows.

Direct labor hrs. $_{\text{(Main plant)}}$ = Direct labor hrs. $_{\text{(Baseline plant)}}$*(Processing rate) ^{p}

Processing rate = Total cells manufactured / Baseline plant cells manufactured

^{P} = Scaling factor for different manufacturing steps lies in between 0.1 to 0.9[275]

The battery manufacturing plant in the master thesis consists of three working shifts with a total of 300 working days. It includes 374 direct labors for the manufacturing of the battery packs. The labor costs for China, India, and Slovakia are calculated on the basis of hourly compensation. These data are extracted from the International labor comparisons data sheet. The table 10.10 shows the detail labor costs for each country and for the per unit battery pack manufacturing.

Description	**CHINA**	**SLOVAKIA**	**INDIA**
Total working days	300	300	300
Total working shifts	3	3	3
No. of direct labors	374	374	374
Direct labor cost, $/hr	4.72	5.25	2.05
Total labor cost, $/Battery pack	85	94	37

Table 10.10 Labor costs[276]

[275] Nelson, P. et. al. (December, 2015)

[276] International labor comparisons (2015)

10.6.3 Variable overhead

The last part of the variable costs is the variable overhead costs. These costs are mainly related to the material overheads, labor overheads and other indirect costs related to the manufacturing process.[277] These costs do not influence the production costs directly but need to be considered while calculating the total cost of manufacturing. The variable overhead costs do not vary directly with the output.[278]

The variable overheads in the cost model basically consist of the material overheads, labor overheads, and the electricity costs incurred in the production processes. The material overheads consist, the indirect materials costs, work in process inventory costs, and material handling costs. The variable overhead costs are calculated with the help of the technique used at AVL List GmbH. The material overheads are calculated at 2% of the total material costs and the labor overheads are 15% of the total direct labor costs.[279] The total costs for all the locations are listed in the table 10.11.

Description	CHINA	SLOVAKIA	INDIA
Variable overhead costs, $/Battery pack	105	121	105

Table 10.11 Variable overhead costs[280]

10.7 Fixed costs

Fixed costs generally do not vary with respect to the quantity of production. These costs include the sales, general and administration costs (SG&A), research and development costs, depreciation costs, profits, and warranty costs.[281] These costs include the taxes, insurance, rental for buildings and equipment, new machines for research, and sales. These costs and the calculation methods are explained in detail in the coming sections.

[277] “Effects of lean Manufacturing”

[278] Joyce, J. “Management accounting – Performance evaluation”

[279] AVL List GmbH, Internal data

[280] AVL List GmbH, Internal data

[281] E &C Antidumping manual (2015)

10.7.1 Sales, general and administration costs

The sales, general and administration costs needed for the operation of an organization. The sales costs are the expenses for advertising, selling, salaries, taxes and other expenses that are related to the selling of the product. The general expenses are the insurance, office rentals and other general expenses for the operation of the company. Administration costs include the salaries of management employees, taxes on the office, and other expenses, which are related to the administration of the company.[282]

The calculation of SG&A costs is done with the help of a markup value. These markup values are provided according to the standards used at the AVL List GmbH. These are basically calculated on the basis of the total variable costs for the battery pack manufacturing. The SG&A costs for the battery pack are calculated as 8.08% of the total variable costs.[283] The costs calculated for the battery pack model with respect to the manufacturing locations are tabulated as follows.

Description	CHINA	SLOVAKIA	INDIA
SG&A Costs, $/battery pack	386	450	414

Table 10.12 SG&A costs[284]

10.7.2 Depreciation costs

Depreciation costs are mainly related to the costs of the assets in the company. The plant equipment, machinery and the building are accounted as an asset to the company. These assets undergo wear and tear throughout the life span due to its utilization over the years. Therefore, the value of these assets decreases over the period of time. The depreciation cost is the value of the assets calculated over this period of time.[285] There are various ways to calculate the depreciation cost of an asset. This includes the lifespan of the machinery, equipment, and the operating plant.

[282] Checkpoint consulting (2003)

[283] AVL List GmbH, Internal data

[284] AVL List GmbH, Internal data

[285] Institute of chartered accountants of India

The depreciation period for the equipment for the battery pack manufacturing plant is considered to be 10 years while for the plant it is considered 20 years. The equipment and the plant are depreciated at straight lines rates with 10% and 20% per year respectively. For all the manufacturing locations the depreciation rate is considered to be the same. The depreciation costs for the straight-line method are calculated as follows.

Depreciation cost = [Total cost of the asset / Lifespan of the asset][286]

Description	CHINA	SLOVAKIA	INDIA
Depreciation cost, $/Battery Pack	383	386	382

Table 10.13 Depreciation costs[287]

10.7.3 Research and development costs

Research is done to gain a technical understanding, which helps in developing a new product and improving the existing products and processes.[288] This involves several activities such as the development of new product, prototyping the product, process and product alternatives, design changes, and construction of new designs. Several types of costs are accounted for all these activities. The research and development department is regarded as one of the most important departments of an organization. The identification of all the research and development activities helps to account for the costs involved.

The various types of costs are included in the research and development activities. The cost of materials required for the research and development, salaries of the employees involved, the equipment needed for the research, depreciation value of the assets involved in the activity, patents, and license fees for a particular product. The research and development costs for the model has been calculated as the 3% of the total

[286] AVL List GmbH, Internal data

[287] AVL List GmbH, Internal data

[288] Australian accounting research foundation (1983)

variable costs.[289] The detailed costs for all the manufacturing locations are mentioned in table 10.14.

Description	CHINA	SLOVAKIA	INDIA
R&D Costs, $/Battery pack	143	167	154

Table 10.14 Research and development costs[290]

10.7.4 Profit and warranty costs

The profit of the manufacturing plant varies with different plants and is considered to be standard as for the battery manufacturing plant. The profit is considered to be 8.28% of the total variable cost.[291] The profit is set according to the standard tier 1 automotive supplier company.

The warranty costs are also considered in the battery pack cost model. In case of the failure of a battery pack, the replacement will include some costs. These costs are added to the warranty costs. The warranty costs include the labor costs for testing and replacing the battery pack, additional material costs, and inventory costs of the replacement battery packs. The average life of a battery pack is generally considered to be 12-15 years. The warranty costs are considered to be 2% of the total variable costs.[292] The costs for the unit battery pack are tabulated in the table 10.15.

Description	CHINA	SLOVAKIA	INDIA
Profit, $/Battery pack	392	457	420
Warranty cost, $/Battery pack	96	111	102

Table 10.15 Profit and warranty costs[293]

[289] AVL List GmbH, Internal data

[290] AVL List GmbH, Internal data

[291] AVL GmbH List, Internal data

[292] AVL GmbH List, Internal data

[293] AVL List GmbH, Internal data

10.7.5 Landed costs

The global manufacturing network consists one of the important cost factors, which is the landed costs. It is very important to consider these costs as these costs have a higher impact on the total cost of the product. In the case of the battery packs considered in the master thesis the focus of sales is in Germany. Germany has been one of the front-runners in the adoption and development of the electric vehicles. Most of the OEMs in Germany are focusing on the new development of battery technologies for the electric vehicle.[294] This is also evident from the point of view of AVL List GmbH. Hence, the focus of sales for the battery pack was considered to be Germany.

The landed cost calculation mainly consists of the value added tax, freight charges, custom duties and the insurance costs for shipping.[295] The landed costs for the battery pack has been calculated on the basis these parameters. The landed costs for the raw materials have also been taken into account and are included in the raw material costs. The vat and custom duty for a lithium ion battery pack to import in Germany are 19.0% and 2.7% respectively.[296] These factors are taken into account while calculating the total landed costs. However, the custom duties and vat are not included in the transport of material between the European union states. Therefore, for the transport from Slovakia to Germany, the custom duties and taxes are exempted. It only includes the freight charges, material handling fees, and insurance charges.

10.8 Summary of results

On the basis of the several calculated costs, the total manufacturing cost of the battery pack is estimated. This can be demonstrated as the total cost of the battery pack system to the OEM. It includes all the important cost factors with respect to the cost model. The cost of the battery pack to the OEM includes the landed costs as well. The cost model is designed according to the sales point of view for the OEMs from Germany. Hence, the landed costs include the value added taxes, custom duties and insurance costs for transporting it to Germany. The total cost of the battery pack provides the deviation in the costs for manufacturing in different locations. The cost of

[294] AVL List GmbH, Internal data

[295] Pumpe, A. (August, 2015)

[296] European commission (January, 2017)

manufacturing in China is estimated to be the lowest cost of the battery pack followed by Slovakia and India. The table 10.16 shows the summary of the costs for all the three manufacturing locations.

Summary of unit costs, $	**CHINA**	**SLOVAKIA**	**INDIA**
Raw material	3400	4053	3740
Purchased Items	1106	1194	1143
Direct labor	85	94	37
Variable overhead	103	119	103
SG&A	379	441	406
Research and development	141	164	151
Depreciation	383	386	382
Profit	385	448	412
Warranty	94	109	100
Landed Costs	1154	350	1230
Total Cost to OEM, $	7230	7358	7705
Total cost to OEM, €	6724	6843	7165
Cost / kWh, €	**168**	**171**	**179**

Table 10.16 Summary of results

The table 10.16 summarizes the total cost calculation of the battery pack. It shows that the lowest cost of manufacturing the battery pack is in China, mainly due to the availability of the cheap raw materials. The landed costs also form a major part of the cost results and prove to be lowest for Slovakia due to the proximity of the customer location. However, the material costs for Slovakia are higher due to the added import duties and taxes. The results also prove that both China and Slovakia are the beneficial manufacturing locations with respect to the total cost of the battery pack. Labor costs, which are one of the most influential factors for best-cost country sourcing, have a higher advantage in India compared to the other two locations. However, the total cost of the battery pack manufacturing for India is the highest among the three locations.

10.9 Cost breakdown

The breakdown of the costs gives a detailed description of the factors contributing to the total costs of the battery pack. The cost evaluation is done with respect to three manufacturing locations. The breakdown of these costs differs to a greater extent for all the three manufacturing locations. China has the major advantage of the raw material costs while Slovakia has proximity to the customer end. On the other hand, India has the advantage of the lowest labor costs of all the three manufacturing locations. The cost benefits provide an edge to the manufacturing countries, which helps to strengthen the value chain. The following figures depict the total breakdown of the costs with respect to the manufacturing locations.

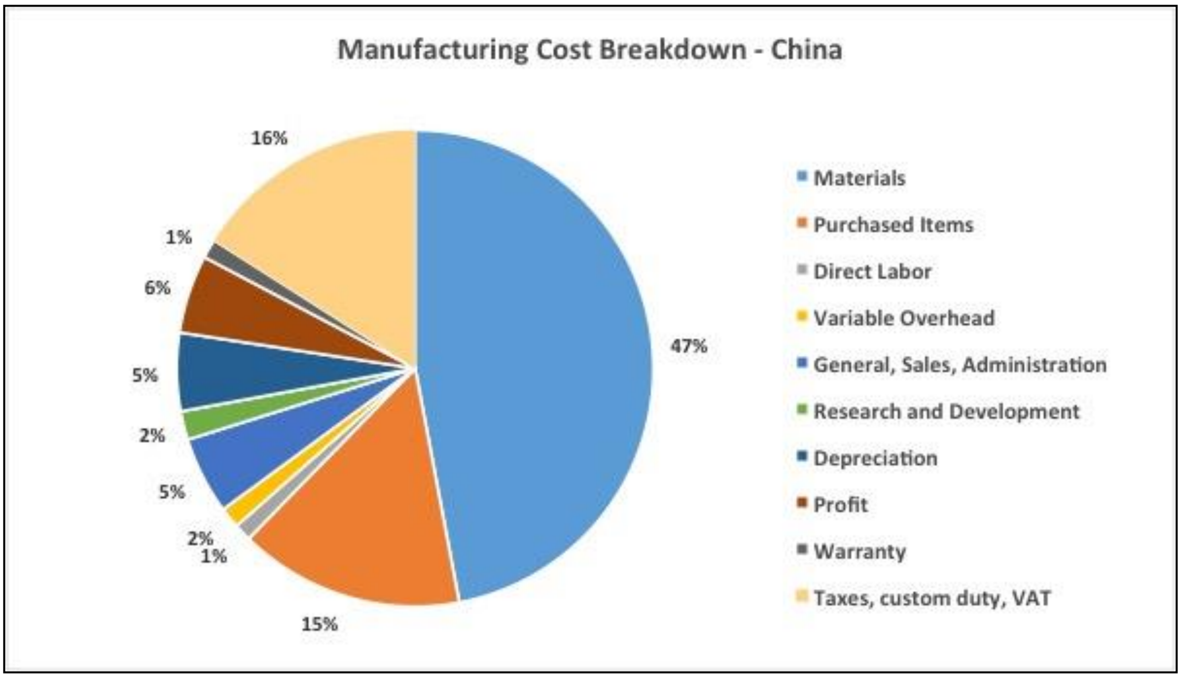

Figure 10.6 Breakdown of costs - China

The major costs for the battery pack are accounted for materials and the purchased items. These constitute more than 60% of the total cost of the battery pack. However, the material costs for manufacturing in China are much less than the other locations. The custom duties, taxes, and VAT cover the next major portion of the costs. This is mainly due to the location of the customer, which is chosen to be Germany in this case. The proximity of the customer has a greater impact on the overall costs.

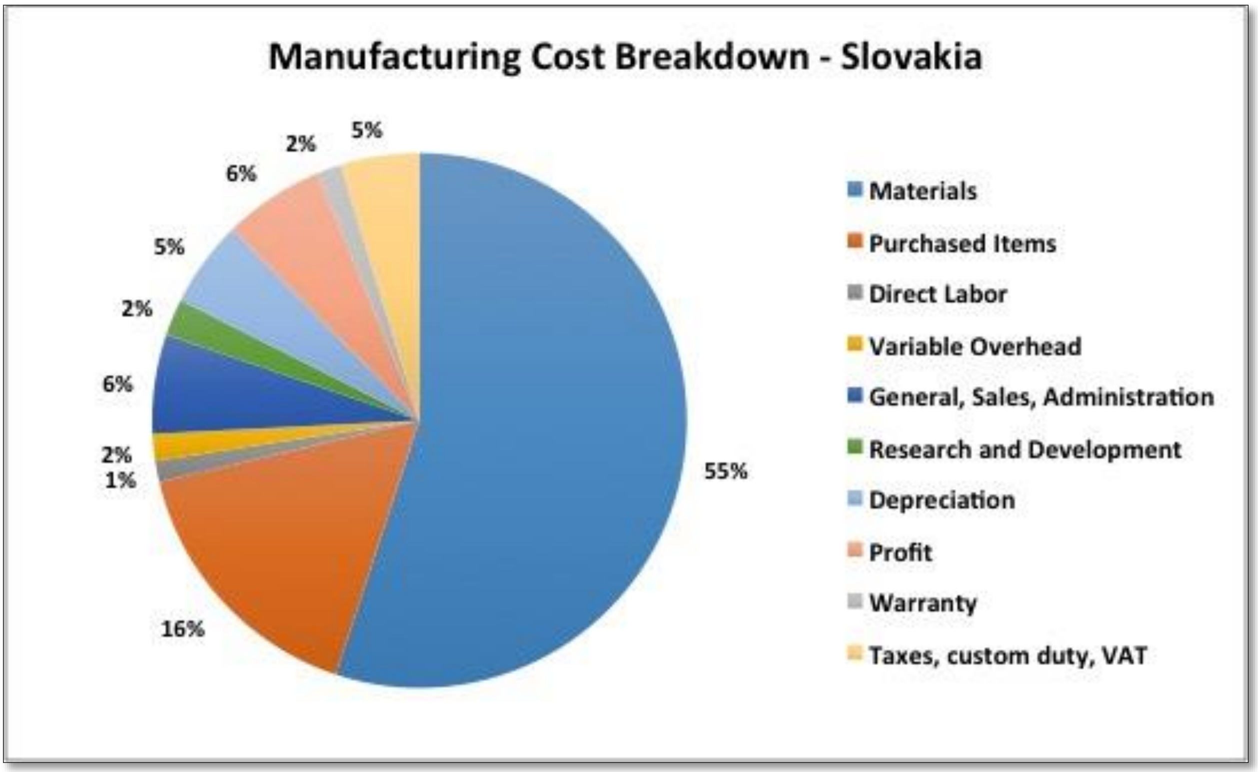

Figure 10.7 Breakdown of costs - Slovakia

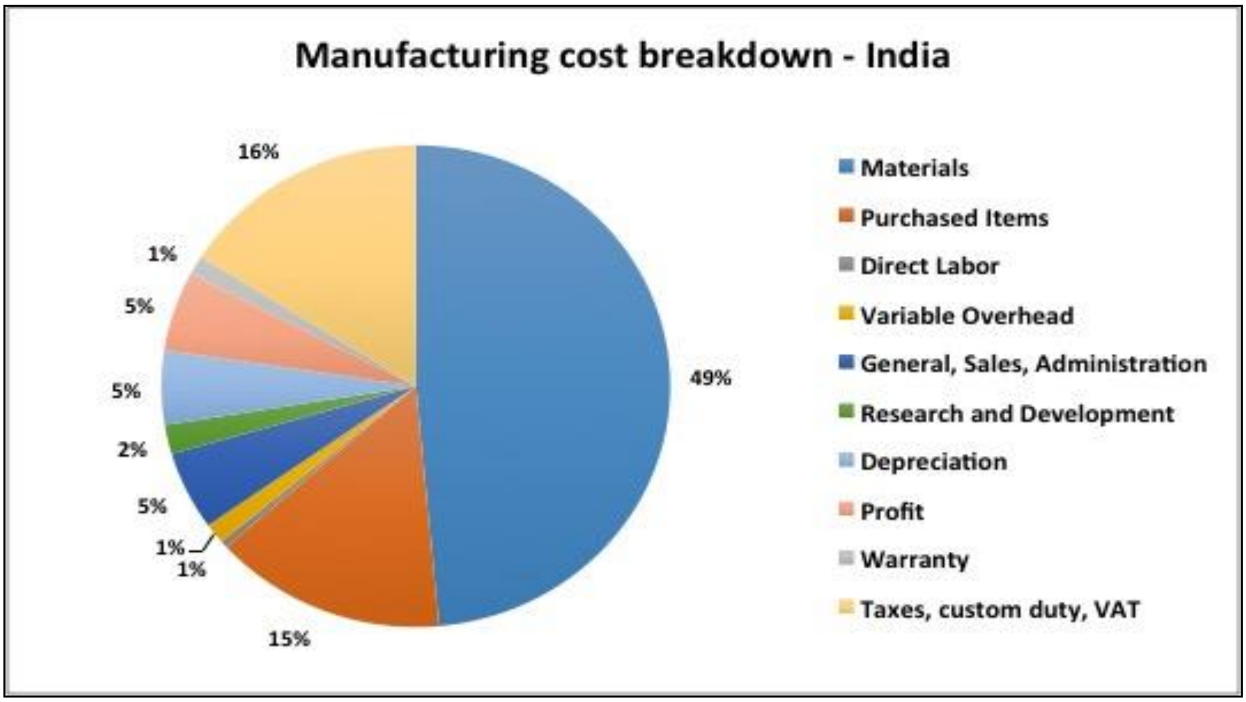

Figure 10.8 Breakdown of costs - India

Another breakdown of costs is calculated with respect to the component, cell manufacturing, module assembly and pack assembly. This helps to understand the cost breakdown with respect to the manufacturing processes. The manufacturing of battery packs is mainly divided into cell manufacturing and pack assembly. The cell manufacturing consists of the raw materials whereas the pack assembly consists of the modules. The breakdown of costs is estimated for all the three manufacturing regions. The major factor of the costs is contributed by the cell manufacturing process for all the manufacturing regions due to the high costs of the raw materials. Table 10.17 shows the breakdown of the cell manufacturing and pack assembly costs.

Description	**CHINA**	**SLOVAKIA**	**INDIA**
Component costs, $	89	105	98
Cell Manufacturing costs, $	23	25	23
Module assembly costs, $	15	15	15
Pack Assembly costs, $	25	29	27

Table 10.17 Cell manufacturing and pack assembly cost breakdown

11 Conclusion

The master thesis aims to understand the supply chain networks and the strategies for the electric vehicle manufacturing. The thesis with the collaboration of AVL List GmbH highlights the concepts of supply chain management for electric vehicle manufacturing. It includes both the qualitative as well as a quantitative approach for finding the solutions. The supply chain networks and strategies for the conventional vehicle manufacturing and electric vehicle have various differences. These differences include different types of alliance strategies with the suppliers, introduction of new suppliers in the electric vehicle manufacturing industry, introduction of new components for electric vehicle manufacturing. These differences have helped to provide a good insight into the electric vehicle manufacturing industry.

The thesis is divided mainly into two parts, which are the theoretical concepts and the empirical data. The empirical part is subdivided into two major parts. One of the part covers the value chain and the supply chain strategies for battery electric vehicle manufacturing. The first part of the theoretical concepts consists of the basic functioning of the electric vehicles. It also focuses on the different types of electric vehicles and its working principle. The main components of the battery electric vehicles are elaborated in detail, which provides the functioning of the components.

The next part of the theoretical framework covers supply chain management concept and its implementation in the manufacturing industry. It also covers the concept of cost modelling, best cost country sourcing and supply chain network concept. These details help to understand the supply chain networks and global manufacturing setup in the automotive industry. The best-cost country sourcing strategy is also briefed in this section. Adoption of this strategy has helped to find the potential manufacturing locations for the battery electric vehicle components. The factors influencing the global manufacturing network are elaborated in detail. This has helped to form a basis for choosing the appropriate manufacturing location for battery electric vehicle components. Cost modelling concept has helped to get an understanding of different cost modelling techniques used to calculate the manufacturing cost.

The results provide the different supply chain network of suppliers throughout the value chain for battery electric vehicle manufacturing. The network consists of the main players in the supply chain right from tier 1 to tier 3 suppliers. The supply chain strategies for the battery electric vehicle manufacturing involve alliances between the tier 1 suppliers and the OEMs. There are basically two types of alliance strategies, which are discussed in detail. The strategy between the battery manufacturers and the OEMs involve joint ventures or collaboration between both of them for battery electric vehicle manufacturing. The other strategy is the traditional strategy between the tier 1 suppliers and the OEMs. This helps the battery manufacturers enter the automotive industry with ease with the help of the tier 1 suppliers.

The value-add analysis for the powertrain components has also been discussed in detail in the empirical study. The analysis evaluated the list of the powertrain components of both the battery electric vehicle and the traditional vehicle, which add the value to the product. The findings of the analysis were that the battery pack added the most value to the battery electric vehicle. Hence, the battery pack was considered to be the powertrain component for the strategic sourcing. The detailed analysis helped to find three manufacturing locations for the battery pack. These manufacturing locations are the so-called best-cost providers, which are China, Slovakia, and India.

The later part of the master thesis focuses on the cost model for the battery pack manufacturing. The cost model evaluates the manufacturing cost of the battery pack in China, Slovakia, and India. It demonstrates the complexity of the battery packs in the form of a cost analysis. The cost model helps AVL List GmbH to get another perspective of cost calculations and benchmark the AVL ProCalc software. It enables to find the potential for cost saving through the best-cost country sourcing. The different costs per unit battery pack for the different manufacturing locations help the OEMs to get a better understanding of the total cost breakdown and strategize the sourcing process for the battery packs.

The cost model proves that the lowest cost of the battery pack is accounted by its manufacturing in China. This is due to the advantages China has over the raw material sources. The next feasible manufacturing location is found out to be Slovakia followed by India. Slovakia has higher costs of raw material and labor but the proximity to the customer helps to reduce the overall costs than India. The cost model highlights the potentials of the battery pack sourcing and total cost breakdown, which allows strengthening the supply chain for battery electric vehicle manufacturing.

The further opportunities deal with finding the cost effective solutions for the entire electric vehicle manufacturing. There are also possibilities to improve the current procedures followed at AVL List GmbH with the help of the cost model. Tweaking of the cost model in some areas can help to achieve the accurate costs and attain a broader perspective. The theoretical, as well as practical solutions can be useful to gain more insights into other powertrain technologies as well.

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List of abbreviations

OEM	Original Equipment Manufacturer
BEV	Battery Electric Vehicle
PHEV	Plug in Hybrid Electric Vehicle
HEV	Hybrid Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride
Li-ion	Lithium Ion
NaNiCl	Sodium Nickel Chloride
ZEBRA	Zero Emission Battery Research
SRM	Supplier Relationship Management
ICE	Internal Combustion Engine
BatPaC	Battery Performance and Calculations
NCA	Nickel Cobalt Aluminum
LMO	Lithium Manganese Spinel
LTO	Lithium Titanate
LFP	Lithium Iron Phosphate
NMP	N- Methyl 2 Pyrrolidone
PVDF	Polyvinylidene Fluoride
SG&A	Sales General and Administration
VAT	Value Added Tax

Appendix

A.1 Cell chemistry

Description	NMC622-G
Positive Electrode	
Active material capacity, mAh/g:	180
Weight %	
Active material	89
Carbon	6
Binder	5
Binder solvent	NMP
Void, Vol% %	32
Density, g/cm^3	
Active material	4.65
Carbon	1.825
Binder	1.77
Negative Electrode	
N/P capacity ratio after formation	1.25
Active material capacity, mAh/g:	360
Weight %	
Active material	95
Carbon	0
Binder	5
Binder solvent	Water
Void, Vol% %	34
Density, g/cm^3	
Active material	2.24
Carbon	1.95
Binder	1.10
Positive Foil	
Material	Aluminum
Thickness, μm	15
Negative Foil	
Material	Copper
Thickness, μm	10
Separator	
Thickness, μm	15
Void, Vol% %	50
Density, g/cm^3	0.46

Description	NMC622-G
Electrolyte density, g/cm^3	1.20
Cell Voltage and Resistance Parameters	
Open circuit voltage at 20% SOC, V	3.565
Open circuit voltage at 50% SOC, V	3.750
Solid state diffusion limiting C-rate (10-s), A/Ah	120
Negative electrode cm^2/cm^3	74,000
Positive electrode cm^2/cm^3	8,900
Sustained power parameter, a	0.40
Sustained power parameter, b	0.236
Electrode system ASI for power, ohm-cm^2	
Selected ASI value	25
At 50% SOC, 2-sec burst	21
At 50% SOC, 10-sec burst	26.6
At 20% SOC range, 10-sec burst	33
At 20% SOC range, 30-sec burst	31.2
ASI correction factor	3
Maximum allowable ASI for limiting capacity	
Electrode system ASI for energy, ohm-cm^2	58.5
Available battery energy, % of total	
Selected % energy	
EV	85
Lithium Content	
Positive electrode, g Li/g active material	0.0836
Negative electrode, g Li/g active material	0
Electrolyte (1.2M LiPF6), g Li/L electrolyte	8.3280

A.2 Battery pack design

Parameters for Finished Cell					
Positive Electrode, g			Weight %	Density	
Active material			89	4.65	308.64
Carbon			6	1.825	20.81
Binder			5	1.77	17.34
Void	Vol. %	32			-
Total			100	2.693	346.79
Negative Electrode, g			Weight %	Density	
Active material			95	2.24	199.37
Carbon			0	1.95	-
Binder			5	1.10	10.49
Void	Vol. %	34			-
Total			100	1.406	209.86
Balance of Cell			Thick., μm	Density	
Positive foil, m^2		Al	15	2.70	1.134
Negative foil, m^2		Cu	10	8.92	1.193
Separator, m^2			15	0.46	2.202
Electrolyte , L				1.20	0.1154
Positive terminal assembly, g					8.9
Negative terminal assembly, g					29.5
Thickness of cell container aluminum layer, µm					100
Thickness of cell container (PET-Al-PP), µm					150
Density of cell container, g/cm3					2.2
Cell container (PET-Al-PP), g					21.6
Cell mass, g					923
Length-to-width ratio for positive electrode					3.00
Default cell thickness target, mm					18
Override cell thickness target, mm					-
Cell thickness, mm					17.993
Thickness of terminal material, mm					1.00

Cell Capacity Parameters	
Positive active material capacity, mAh/g:	180
Positive electrode capacity, Ah/cm^3	0.431
Negative active material capacity, mAh/g:	360
Negative electrode capacity, Ah/cm^3	0.481
Negative-to-positive capacity ratio after formation	1.25
Cell Voltage and Resistance Parameters	
OCV at full power, V	3.565
Open circuit voltage at 50% SOC, V	3.750
Electrode system ASI for energy, $ohm\text{-}cm^2$	58.5
Excess negative area, %	3.35
Target % OCV at full power	80
% OCV at full power adjusted for thickness limit	94.6
Battery open circuit voltage, V	360.0
Battery Input Parameters	
Vehicle type (microHEV, HEV-HP, PHEV, EV)	EV
Pack heat transfer fluid (EG-W, CA, CoolA)	EG-W
Designated duration of power pulse for application (10 or 2), s	10
Target battery pack power, kW	80
Approximate target power for 30-sec pulse (EV application), kW	64
Estimated battery power at target % OCV, kW	236
Number of cells per module	16
Number of cells in parallel	2
Number of modules in row	2
Number of rows of modules per pack	6
Number of modules per battery pack	12
Number of modules in parallel	1
Number of packs per vehicle (parallel or series)	1
Parallel packs (P) or series (S)	-
Cells per battery pack	192
Total cells per battery system	192
Battery pack insulation thickness, mm	10
Battery jacket total thickness, mm	14
Number of batteries manufactured per year	**50,000**

A.3 Cost input

Unit Cell Materials Cost	**CHINA**	**SLOVAKIA**	**INDIA**
Positive Electrode, $/kg			
Active Material	20	24	22
Carbon	10	12	11
Binder PVDF	20	24	22
Binder Solvent (NMP)	5	6	5.5
Negative electrode material, $/kg			
Active Material	14	16.8	15.4
Carbon Black	10	12	11
Binder	20	24	22
Binder Solvent	0	0	0
Positive current collector foil, $/m2	0.3	0.36	0.33
Negative current collector foil, $/m2	1.3	1.56	1.43
Separators, $/m2	1.2	1.38	1.32
Electrolyte, $/L	18	21.6	19.8
Unit Cell Hardware Costs			
Positive terminal, $/kg	3	3.15	3.075
Negative terminal, $/kg	5	5.25	5.125
Cell Container, $/kg	2	2.1	2.05
Alum. heat conductor, $/kg	3	3.15	3.075
(or thermal group enclosure)			
Module Purchased Materials Cost			
State-of-charge regulator			
Cost per cell, $	2.5	2.625	2.5625
Plus cost per capacity, $/Ah	0.01	0.01	0.01
Module terminals			
Cost per mass, $/kg	4	5	4.5
Plus cost per module, $	0.75	0.75	0.75
Provision for gas release, $/module	1.5	1.5	1.5
Module enclosure materials			
Cost per mass, $/kg	2.5	3.5	3
Plus cost per module, $	1	1	1
Battery Purchased Materials Cost			

Module Inter-connectors wiring	**CHINA**	**SLOVAKIA**	**INDIA**
Cost per mass, $/kg	3.5	4.5	4
Plus cost per interconnect, $	1	1	1
compression plates, $,kg	2	2	2
Battery terminals			
Cost per battery, $	10	15	12.5
Plus cost per capacity, $/A	0.02	0.02	0.02
Bus bar for packs, $ each	10	15	12.5
Battery Jacket			
Cost per battery jacket weight, $/kg	7	8.5	7.5
Plus cost per battery, $	25	33.5	31.5

Cost Rates for Manufacturing			
Investment Costs	**China**	**Slovakia**	**India**
Cost of building (including land and utilities), $/m^2	300	400	250
Launch Cost rates			
% of direct annual materials and purch.items cost, %	5	5	5
% of direct labor plus variable overhead, %	10	10	10
Working capital, percent of annual variable cost, %	15	15	15
Unit Cost of Battery Pack			
Variable Cost			
Direct labor rate, $/hr	4.72	5.25	2.05
Variable overhead rate			
% of direct labor	15	15	15
% of material and purchased parts	2	2	2
Fixed Expenses			
SG&A rates, Percent of total variable costs, %	8.08	8.08	8.08
R & D rate, % of total variable costs	3	3	3
Depreciation rates			
Percent of capital equipment investment, %	10.0	10.0	10.0
Percent of building investment (20-year rate), %	5	5	5
Profits After Taxes, % of total variable costs	8.26	8.26	8.26
Warranty Cost, % added to price	2	2	2

A.4 Manufacturing cost calculations

Annual Processing Rates	**CHINA**	**SLOVAKIA**	**INDIA**
No. of battery packs manufactured per year	50000	50000	50000
Energy, kWh per year	1969224	1969224	1969224
Number of accepted cells per year	9600000	9600000	9600000
Number of cells adjusted for yield	10105263	10105263	10105263
Electrode area, m^2 per year	20677190	20677190	20677190
Positive active material, kg per year	3382764	3382764	3382764
Negative active material, kg per year	2185122	2185122	2185122
Binder solvent, kg per year	4561030	4561030	4561030
Dry room operating area, m^2	4259	4259	4259
Total Cell Materials per Accepted Cell			
Positive Electrode Materials (dry), g			
Active Material	352.37	352.37	352.37
Carbon	23.76	23.76	23.76
Binder PVDF	19.80	19.80	19.80
Binder Solvent (NMP)	475.11	475.11	475.11
Total (dry)	395.92	395.92	395.92
Negative Electrode Materials (dry), g			
Active Material	227.62	227.62	227.62
Carbon Black	0.00	0.00	0.00
Binder	11.98	11.98	11.98
Binder Solvent (water)	287.52	287.52	287.52
Total (dry)	239.60	239.60	239.60
Positive current collector (aluminum foil), m^2	1.32	1.32	1.32
Negative current collector (copper foil), m^2	1.39	1.39	1.39
Separators, m^2	2.37	2.37	2.37
Electrolyte, L	0.13	0.13	0.13
Annual Cell Materials Rates			
Positive Electrode			
Active Material, kg	3382763.97	3382763.97	3382763.97
Carbon, kg	228051.50	228051.50	228051.50
Binder PVDF, kg	190042.92	190042.92	190042.92
Binder Solvent (NMP) makeup, kg	22805.15	22805.15	22805.15

Annual Processing Rates	**CHINA**	**SLOVAKIA**	**INDIA**
Negative Electrode Material, kg			
Active Material (graphite), kg	2185122.49	2185122.49	2185122.49
Binder PVDF, kg	115006.45	115006.45	115006.45
Positive current collector (aluminum foil), m2	12702898	12702898	12702898
Negative current collector (copper foil), m2	13364580	13364580	13364580
Separators, m2	22707534	22707534	22707534
Electrolyte, L	1240633.25	1240633.25	1240633.25
Positive terminal assemblies	10105263	10105263	10105263
Negative terminal assemblies	10105263	10105263	10105263
Cell Containers	10105263	10105263	10105263
Aluminum thermal conductor	9600000.00	9600000.00	9600000.00
Positive binder solvent evaporated, kg	4561030.07	4561030.07	4561030.07
Negative binder solvent evaporated, kg	2760154.72	2760154.72	2760154.72

Cell Materials Cost, $/cell	**CHINA**	**SLOVAKIA**	**INDIA**
Positive Electrode (dry)			
Active Material	6.58	7.90	7.24
Carbon	0.24	0.29	0.26
Binder PVDF	0.40	0.48	0.44
Binder Solvent (NMP)	0.01	0.01	0.01
Negative electrode material (dry)			
Active Material	3.00	3.60	3.30
Carbon Black	0.00	0.00	0.00
Binder	0.24	0.29	0.26
Positive current collector	0.40	0.48	0.44
Negative current collector	1.81	2.17	1.99
Separators	2.84	3.26	3.12
Electrolyte	2.19	2.63	2.41
Positive terminal assembly, $/unit	0.25	0.25	0.25
Negative terminal assembly, $/unit	0.36	0.37	0.37
Cell container, $/unit	0.22	0.22	0.22
Total cost of cell winding materials, $	17.71	21.11	19.48
Total cost of cell materials, $	18.54	21.95	20.32

Cost of Module Mtl and Purchased Items, $	**CHINA**	**SLOVAKIA**	**INDIA**
Aluminum thermal conductors (each)	0.18	0.18	0.18
Aluminum thermal conductors/module	2.85	2.92	2.89
Cell group interconnects (copper)	5.66	5.66	5.66
Module state-of-charge regulator	28.89	29.89	29.39
Module terminals	0.88	0.91	0.90
Provision for gas release	1.50	1.50	1.50
Module enclosure	1.92	2.29	2.10
Total cost per module	41.71	43.18	42.44
Cost of Battery Pack Materials, $			
Module Inter-connectors and signal wiring	19.56	23.84	21.56
Module compression plates	7.01	7.01	7.01
Battery terminals	16.00	21.00	18.50
Baseline thermal system	120.00	120.00	120.00
Heating system	20.00	20.00	20.00
Battery jacket	262.08	321.38	285.52
Total cost per battery pack	444.65	513.24	472.59
Total cost of materials for cells and battery pack, $	4505.54	5246.44	4883.26

Battery Assembly Costs	**Baseline**		**China, Slovakia, India**
Operation (Pertinent rate)	**Plant**	**p**	
Receiving (Energy/yr)			
Volume ratio (volume/baseline volume)			2.26
Direct Labor, hours/year	14400	0.4	19971
Capital Equipment, million$	3.6	0.6	5.88
Plant Area, square meters	900	0.5	1354.49
Electrode Processing			
Materials preparation			
Positive materials (positive mass/yr)			
Volume ratio (volume/baseline volume)			1.98
Direct Labor, hours/year	14400	0.5	20239
Capital Equipment, million$	2	0.7	3.22
Plant Area, square meters	600	0.6	902.68

Operation	Baseline	p	China, Slovakia, India
Negative materials (negative mass/yr)			
Volume ratio (volume/baseline volume)			1.81
Direct Labor, hours/year	14400	0.5	19384
Capital Equipment, million$	2	0.7	3.03
Plant Area, square meters	600	0.6	857.14
Electrode coating			
Positive materials (area/yr)			
Volume ratio (volume/baseline volume)			2.52
Solvent evaporated, kg/m^{2}yr	0.28		0.22
Direct Labor, hours/year	28800	0.5	45708
Capital Equipment, million$	8	0.8	15.96
Plant Area, square meters	750	0.8	1570.44
Negative materials area/yr)			
Volume ratio (volume/baseline volume)			2.52
Solvent evaporated, kg/m^{2}yr	0.18		0.13
Direct Labor, hours/year`	28800	0.5	45708
Capital Equipment, million$	8	0.8	15.68
Plant Area, square meters	750	0.8	1570.44
Binder solvent (NMP) recovery (kg/yr)			
Volume ratio (volume/baseline volume)			1.98
Direct Labor, hours/year	28800	0.4	37813
Capital Equipment, million$	5	0.6	7.52
Plant Area, square meters	225	0.6	338.50
Calendering			
Positive materials (area/yr)			
Volume ratio (volume/baseline volume)			2.52
Direct Labor, hours/year	14400	0.5	22854
Capital Equipment, million$	1	0.7	1.91
Plant Area, square meters	225	0.6	391.65
Negative materials area/yr)			
Volume ratio (volume/baseline volume)			2.52
Direct Labor, hours/year	7200	0.5	11427
Capital Equipment, million$	1	0.7	1.91

Plant Area, square meters	225	0.6	391.65
Operation	**Baseline**	**p**	**China, Slovakia, India**
Inter-process materials handling (area/yr)			
Volume ratio (volume/baseline volume)			2.52
Direct Labor, hours/year	28800	0.7	54983
Capital Equipment, million$	1.5	0.7	2.86
Plant Area, square meters	900	0.6	1566.61
Electrode Slitting (area/yr)			
Volume ratio (volume/baseline volume)			2.52
Direct Labor, hours/year	28800	0.5	45708
Capital Equipment, million$	2	0.7	3.82
Plant Area, square meters	300	0.6	522.20
Vacuum Drying of Electrodes			
Volume ratio (volume/baseline volume)			2.52
Direct Labor, hours/year	14400	0.5	22854
Capital Equipment, million$	1.6	0.7	3.05
Plant Area, square meters	300	0.6	522.20
Control Laboratory			
Volume ratio (volume/baseline volume)			2.26
Direct Labor, hours/year	28800	0.5	43344
Capital Equipment, million$	1.5	0.7	2.66
Plant Area, square meters	300	0.6	489.96
Cell Assembly in Dry Room			
Cell stacking (number of cells)			
Volume ratio (volume/baseline volume)			1.60
Cell Capacity, Ah	40	0.3	55.56
Direct Labor, hours/year	36000	0.7	50025
Capital Equipment, million$	4	0.8	6.43
Plant Area, square meters	600	0.8	873.87
Current collector welding (number of cells/yr)			
Volume ratio (volume/baseline volume)			1.60
Direct Labor, hours/year	36000	0.7	50025
Capital Equipment, million$	4	0.8	5.83
Plant Area, square meters	600	0.8	873.87

Inserting cell in container (number of cell/yr)			
Volume ratio (volume/baseline volume)			1.60
Operation	**Baseline**	**p**	**China, Slovakia, India**
Direct Labor, hours/year	21600	0.5	27322
Capital Equipment, million$	3	0.7	4.17
Plant Area, square meters	600	0.6	795.47
Electrolyte filling, and cell sealing (no. of cells/yr)			
Volume ratio (volume/baseline volume)			1.60
Direct Labor, hours/year	36000	0.5	45537
Capital Equipment, million$	5	0.7	6.95
Plant Area, square meters	900	0.6	1193.20
Dry Room Control (operating area, sq. meters)			
Volume ratio (volume/baseline volume)			1.42
Direct Labor, hours/year	7200	0.4	8283
Capital Equipment, million$	6	0.6	7.40
Plant Area, square meters	100	0.4	115.04
Formation Cycling (number of cells/yr)			
Volume ratio (volume/baseline volume)			1.60
Cell Capacity, Ah	40	0.3	55.56
Direct Labor, hours/year	57600	0.7	80040
Capital Equipment, million$	30	0.8	48.22
Plant Area, square meters	2200	0.8	3536.05
Final Cell Sealing (number of cells/yr)			
Volume ratio (volume/baseline volume)			1.60
Direct Labor, hours/year	14400	0.5	18215
Capital Equipment, million$	2	0.7	2.78
Plant Area, square meters	450	0.6	596.60
Charge Retention Testing (number of cells/yr)			
Volume ratio (volume/baseline volume)			1.60
Direct Labor, hours/year	21600	0.4	26068
Capital Equipment, million$	4.75	0.7	6.60
Plant Area, square meters	900	0.6	1193.20
Module Assembly (number of cells/yr)			
Volume ratio (volume/baseline volume)			1.60

Direct Labor, hours/year	43200	0.5	54644
Capital Equipment, million$	6	0.7	8.34
Plant Area, square meters	600	0.6	795.47
Operation	**Baseline**	**p**	**China, Slovakia, India**
Battery Pack Assembly and Testing			
Volume ratio (volume/baseline volume)			1.60
Number of modules per Pack	4	0.3	12.00
Direct Labor, hours/year	43200	0.5	54644
Capital Equipment, million$	6	0.7	11.59
Plant Area, square meters	900	0.6	1193.20
Rejected Cell and Scrap Recycle (no. of cells/yr)			
Volume ratio (volume/baseline volume)			1.60
Direct Labor, hours/year	36000	0.7	50025
Capital Equipment, million$	2.5	0.7	3.47
Plant Area, square meters	600	0.6	795.47
Shipping (energy/yr)			
Volume ratio (volume/baseline volume)			2.26
Direct Labor, hours/year	28800	0.5	43344
Capital Equipment, million$	5	0.7	8.86
Plant Area, square meters	900	0.6	1469.88
Summary for Battery Pack			
Direct Labor, hours/year			**898164**
Capital Equipment, million$			**188.14**
Plant Area, square meters			**23909**

A.5 Summary of results

Calculated Battery Parameters	**CHINA**	**SLOVAKIA**	**INDIA**
Vehicle electric range, miles	167	167	167
Vehicle electric range, km	269	269	269
Number of battery packs	1	1	1
Number of cells per pack	192	192	192
Battery system total energy storage, kWh	40	40	40
Cell capacity, Ah	56	56	56
Cell group capacity, Ah	111	111	111
Battery system capacity, Ah	111	111	111
Nominal battery system voltage,V	360	360	360
Required battery system power, kW	80	80	80
Battery system volume (all packs), L	136	136	136
Battery system mass (all packs), kg	236	233	233
Investment Costs			
Capital equipment cost including installation, mil$	188.1	188.1	188.1
Building, Land and Utilities			
Area, m2	23909	23909	23909
Cost, $/m2	300	400	250
Building investment, mil$	7.2	9.6	6.0
Launch Costs			
Rate: 5% of direct annual materials + 10% of other annual costs			
Total, million$	12.2	14.2	12.9
Working capital (15% of annual variable costs), mil$	35.2	40.9	37.7
Total investment, mil$	242.7	252.8	244.7
Unit Cost of Battery Pack, $			
Variable Cost			
Materials and Purchased Items			
Cell materials	3400	4053	3740
Cell purchased Items	160	162	161
Module	500	518	509
Battery pack	445	513	473

Total	4506	5246	4883
Variable Costs	**CHINA**	**SLOVAKIA**	**INDIA**
Direct Labor			
Electrode processing	31	34	13
Cell assembly	17	19	7
Formation cycling, testing and sealing	12	13	5
Module and battery assembly	10	11	4
Cell and materials rejection and recycling	5	5	2
Receiving and shipping	6	7	3
Control laboratory	4	5	2
Total	85	94	37
Variable Overhead	103	119	103
Total Variable Cost	4693	5460	5023
Fixed Expenses			
General, Sales, Administration	379	441	406
Research and Development	141	164	151
Depreciation	383	386	382
Total Fixed Expenses	903	991	939
Profits after taxes	385	448	412
Total unit cost per pack not incl. warranty, $	**5981**	**6898**	**6374**
Summary of Unit Costs, $			
Materials	3400	4053	3740
Purchased Items	1106	1194	1143
Direct Labor	85	94	37
Variable Overhead	103	119	103
General, Sales, Administration	379	441	406
Research and Development	141	164	151
Depreciation	383	386	382
Profit	385	448	412
Warranty	94	109	100
Taxes, custom duty, VAT	1154	350	1230
Price to OEM for battery pack, $	**7230**	**7358**	**7705**
Price to OEM for battery pack, €	**6724**	**6843**	**7165**
Price to OEM, €/kWh	**168**	**171**	**179**

A.6 Questionnaire

The following are the excerpts from the questionnaire with Mr. Wolfram Irsa, who is the in charge of supply chain management division at AVL List GmbH.

1. What is the role of AVL List GmbH in the field of electric vehicles and its supply chain network?

Answer: AVL has the unique position of being able not only to develop single components of a modern powertrain, but also to optimize them on a system level by leveraging the entire supply chain. The integration of these components to a balanced overall system is a major customer benefit. AVL designs and develops e-drive solutions, which are well tailored to the customer specific applications, whether in hybrids, e-vehicles or auxiliaries.

2. How does this research work help AVL List GmbH for its development in electric vehicles?

Answer: This research work helps to develop a deeper understanding of the characteristic effect on the supply chain of electric vehicle manufacturing compared to ICE (internal combustion engine) vehicle manufacturing. In particular, the work is important to find out how best cost providers contribute to the manufacturing of the battery packs for battery electric vehicles.

3. What are the benefits of the cost model used for manufacturing of battery packs?

Answer: The cost model demonstrates impressively the complexity of sophisticated battery packs. The many different views to the data allow a tailored reasoning about feasible manufacturing options. Therefore, the found information is useful to challenge existing cost models in the AVL ProCalc landscape.

4. Are there any other aspects/assumptions, which can be included in the cost model?

Answer: The scope of the model is well defined. Consequently, the expectations on the cost model have been clearly expressed and are fully met. There are no further aspects/assumptions.

5. Is there any further research work, which will be done in the future on the basis of the results of this research work?

Answer: Yes, there are opportunities for future research work. The cost model enables to benchmark existing AVL ProCalc routines. The thoroughness of the cost model is impressive, which helps to reflect and improve current procedures. Additionally, the research work opens the door to develop further a comprehensive cost model reaching from the electric powertrain to an entire electric vehicle.