Automotive Weight Management: A Performance Based Approach

by

Zhang Xingtian

Thesis for Mater Degree in Automotive Engineering

Politecnico di Torino

March, 2018

Supervisor from FCA: Eng. Antonio Di Tella

Supervisor from Politecnico di Torino: Prof. Giovanni Belingardi

Acknowledgements

There are many people and organizations that I would like to give my sincere appreciation. First, I would like to thank my university Politecnico di Torino, which gives me my 6-year higher education. The long-standing polytechnic culture imperceptibly influenced me and made me become a better person.

I would like to thank FCA for providing the chance of the thesis in company. This experience is unique and significantly influenced my life. During the stage, I have touched the world of work and acquired precious working experiences in automotive industry. I would like to give my special thank to my tutor in company, my “shifu”, Mr. Antonio Di Tella. Thank you for giving me this precious experience in my life and thank you for giving me the guidance and teaching me the knowledge which cannot be got from classrooms. I also would like to thank the other people in Weight Management group: Francesco Piperata, Davide De Luca, Maurizio Martinez and Mauro Moscarelli (maybe the spells have some problems…) who give me care and technical helps during the stage.

I would like give my sincere acknowledgement to my academic advisor Professor Belingardi. Thank you for giving me the approval and the academic guidance. I apologize to you that I haven’t informed you my progress in time, and thank you for your lenient tolerance. And I would like to thank all of the professors and lecturers during the MSc programme. Thank you all for imparting your professional knowledge to me.

Special thank to my Chinese colleagues Gao Kai, Han Peiheng, Li Hangzhang, Ma Yi, Zhang Mengyuan, who enrolled the second year of the orientation Vehicle System Development in the academic year 2016/17. Thank you all for your company and helps in the hardest days. Although now we are in different corners in the world, our hearts are together every second. I hope we can barbecue together again, with all of the 6 people, on someday in the future.

I also would like to thank my best friends who I have met during my time of senior high school. Although the time has passed, I know we are still missing, encouraging and competing with each other without any word. You are the reason why I persist till now. Thank you brothers and sisters. I miss you all.

Finally, I would like to thank my family, which gives me all. The emotion of my appreciation is hard to expressed by my poor language. The only things that I can do is to improve myself, and repay you in the future.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AHP	Accelerator Heel Point
BEV	Battery Electric Vehicle
BIW	Body In White
BOF	Ball Of Foot
BOFRP	Ball Of Foot Reference Point
CAD	Computer-Aided Design
CCP	Customer Care Profile
CO_2	Carbon Dioxide
ECE	Economic Commission for Europe
EMEA	Europe, The Middle East And Africa
EPA	Environmental Protection Agency
Euro NCAP	The European New Car Assessment Programme
FCA	Fiat Chrysler Automobiles
FL	Facelift
FPA	Floor Plane Angle
FRP	Floor Reference Point
GAWR	Gross Axle Weight Rating
GVWR	Gross Vehicle Weight Rating
HEV	Hybrid Electric Vehicle
HOS	Heel Of Shoe
HVAC	Heating, Ventilation and Air Conditioning
ICE	Internal Combustion Engine
Li-ion	Lithium Ion
MCA	Mid Cycle Action

MH	Metal Hydride
MR	Model Responsible
NEDC	New European Driving Cycle
NHRA	National Hot Rod Association
NiMH	Nickel Metal Hydride
NVH	Noise, Vibration and Harshness
OEM	Original Equipment Manufacturer
PC	Project Chief
PE	Polyethylene
PF	Platform
PP	Product Planning; Polypropylene
PR	Project Responsible
PS	PreSeries
SAE	Society of Automotive Engineers
SEI	Surface-Electrolyte-Interface
SgRP	Seating Reference Point
TWC	Test Weight Class
UDC	Urban Driving Cycle
UN	Units
VIR	Vehicle Integration Responsible
VP	Verification of Process Build
VW	Volkswagen
WE	Weight Engineer
WLTP	Worldwide harmonized Light vehicles Test Procedure

ABSTRACT

Weight is an important property of an automotive since it affects directly the fuel consumption, carbon dioxide emission and the performance of acceleration of the vehicle. The weight of a vehicle is obviously the sum of the weights of all of the systems, subsystems and components of the whole vehicle, reflects a universal choice for the weight of each component. In general, a lighter vehicle means it has the possibility to reach a higher performance of acceleration and also fuel consumption and the CO_2 emission, since the mass of the vehicle is lower and therefore the power and the energy that needed for accelerating the vehicle is lower and the rolling resist which depends on the weight of the vehicle is lower. In a certain automotive segment, comparing with the average, a vehicle with a lower weight but has sufficient even better performances will be a successful product in target setting point of view.

For a system or, a subsystem or, a single component, its performance is linked more or less with its mass. In people's mind, a heavier component or system should have a better performance than a lighter one. It is generally true however not exactly. In some case a system with a lower mass may have a better performance due to its special design and/or materials. Starting from this, a concept of weight efficiency is drawn. Similar with price/performance ratio which people usually talk about, the weight efficiency is the ratio between the considered performance and the weight of the corresponding system/subsystem or certain components to assess the effectiveness of the weight. For automotive weight management, when we say performances, one significant step is evaluating the weight efficiency for one or more performances. The weight efficiency is a powerful tool for target setting of a new product and product planning.

For facing the facts that the less and less petrol resources of the earth and the increase of the greenhouse effect, the whole automotive industry plays a non-substitutable role. For conventional fuel vehicles, reducing weight, or increasing the weight efficiency, is the necessary consideration to deal with the problem of fuel consumption and to reach the CO_2 emission target. In the last decade, more and more countries started and prepared to introduce policies to encourage wide range application of battery electric vehicles (BEV). BEV has advantages of zero in-situ emission and high energy conversion efficiency. However, the two biggest drawbacks of BEV are its short range compared with conventional vehicles and the high weight of its battery pack. Therefore, for weight management of a BEV in the field of performances, not only traditional

performances but also the performance about range, i.e. autonomy performance, should be taken into account. Also, how to handle the relationship between the weight of the battery pack and the range covered by the vehicle is a challenge for both battery pack suppliers and OEMs.

CHAPTER 1

Introduction to Weight Management

The contains of this chapter come from the internal harmonized documents and standards of FCA for the area EMEA. This chapter is only for introducing the activities needed for weight management inside FCA.

1.1 Weight management process

Weight management is to define the operation rules, the institutional tasks/targets for the management of the vehicle weight during the various phases of the development process. Starting from the concept phase, weight management process is accompanied with all of the phases of production development process. The activities of weight management is shown in Figure 1.1.

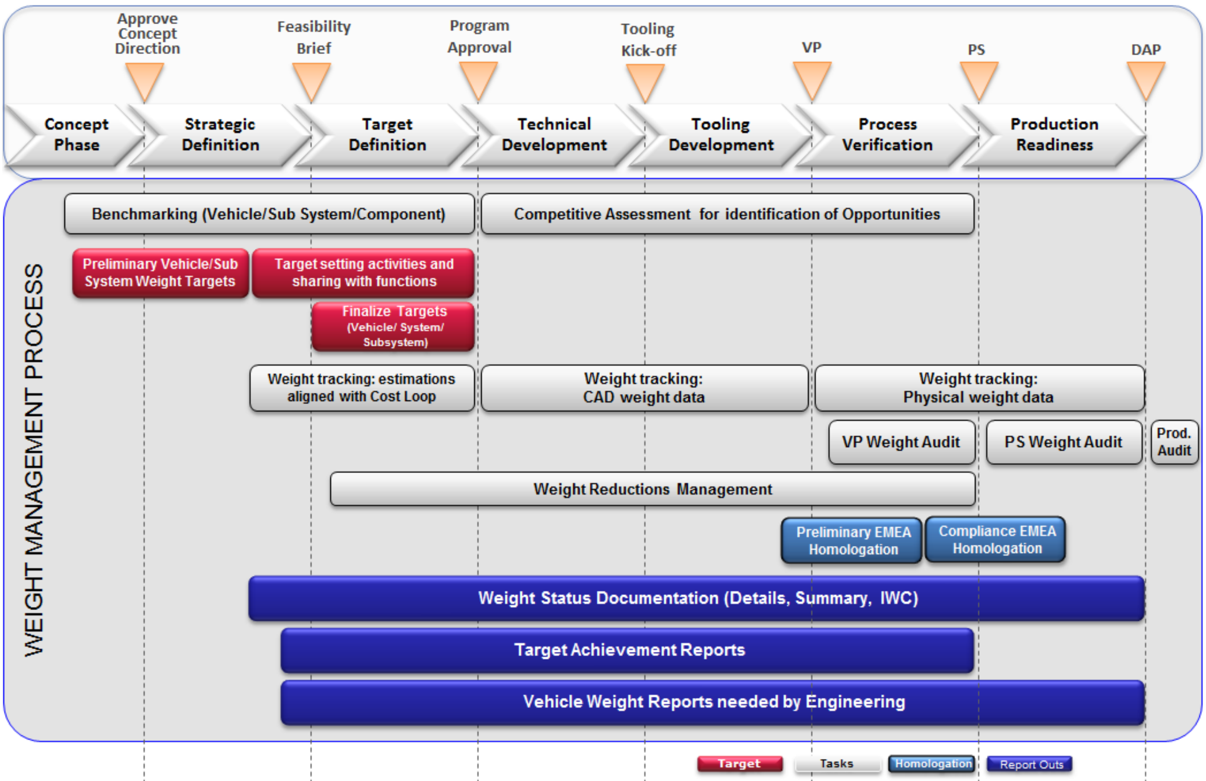


Figure 1.1, Weight management process overview.

In weight management process, benchmarking, target setting, weight tracking, weight reductions and risk management, production audit and homologation are the main activities. The criteria of them inside FCA will be introduced in this chapter below briefly.

1.2 Benchmarking

The purpose of benchmarking is to analyse the vehicles of competitors and collect data to be used in the target definition process. A competitive assessment of competitor vehicles allows for generation of the ideas for weight reduction.

Benchmarking is typically performed between concept definition and target definition phases to align with the target setting process. It should be payed attention that, benchmarking could have a long period may continue until Job 1.

Several tools are utilized by the weight engineer for performing the analysis. The most powerful tools for weight management are density chart and absolute weight chart. They will be introduced briefly below.

1.2.1 Density chart

A density chart is a plot of the base weight (FCA definition, the weight of the vehicle including standard equipment and full fluids and it does not include passengers, cargo or any optional equipment) versus the volume or foot print of the studied vehicles. The use of a density chart is to study the competitive market and to define the reference competitor defined in the target setting process, based on weight. The density chart should include the vehicles identified as the main competitors for the Product Briefing published by Vehicle Line Product Planning.

An example of density chart is shown in Figure 1.2 below. In the chart, several products, including FCA’s and competitors’ vehicles, are represented as points whose coordinates depend on the weight and the volume of the corresponding vehicle. The parallel lines which have a certain inclination are isodensity lines, to assist to recognize the density state of a certain vehicle or to compare the density states of two or more vehicles. If a vehicle lies on or near an isodensity line which has a lower position, it means that this vehicle has a better weight/volume efficiency.

The data used for constructing density chart should be retrieved from reliable sources and properly normalized based on comparable models with similar powertrain, trim level, contents, etc. Some examples of data sources:

- For dimensions: Dimensional Portfolio document (official FCA EMEA source);

- For weight: measurements of sample vehicles; A2mac1; Sala Analisi Concorrenza database (the database of EMEA vehicles production weights).

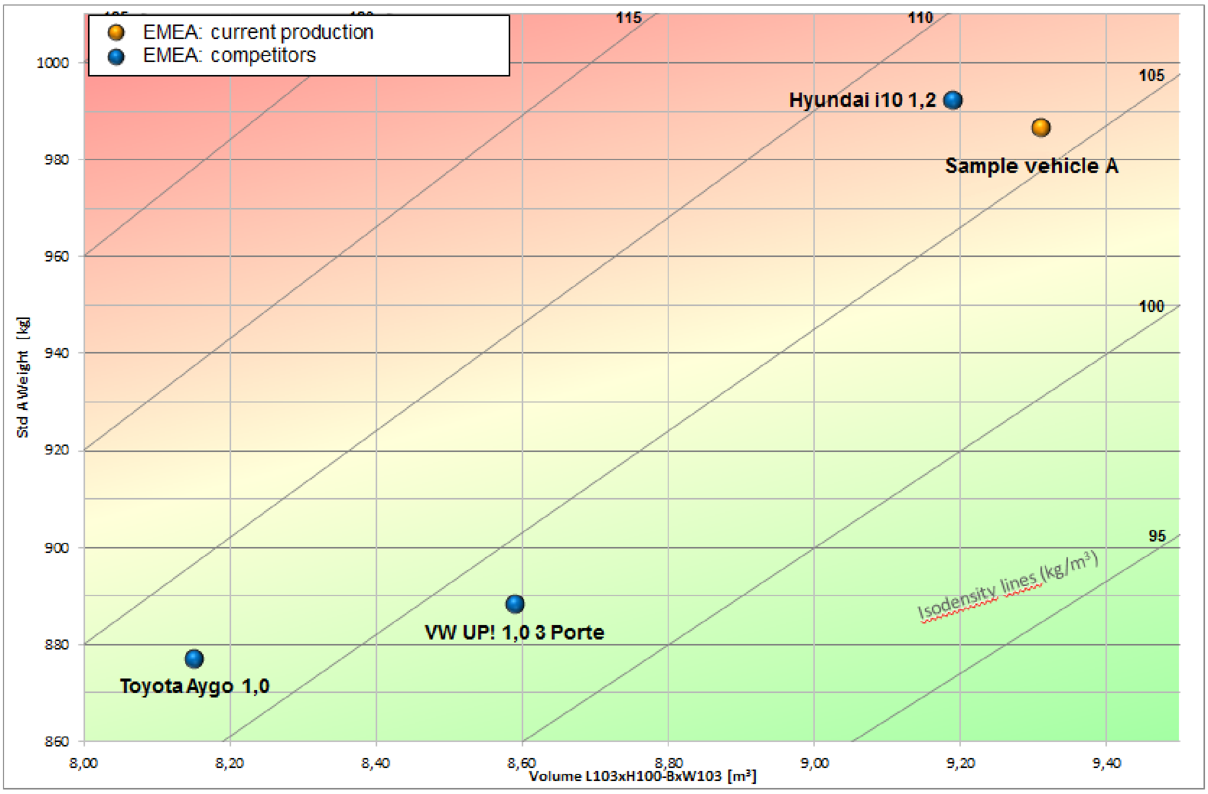


Figure 1.2, Example of density chart.

1.2.2 Absolute weight chart

The absolute weight chart is a plot of the weight of competitors' vehicles also based on the comparable vehicles with similar powertrain, trim level, contents, etc. The purpose of absolute weight chart is to analyse the market status. An example of absolute weight chart is shown below in Figure 1.3.

1.3 Target setting

The purpose of target setting process is to determine the weight target for each system. It starts from the concept phase and ends at the target definition phase. It should be noticed that the target setting processes for new vehicle and carryover vehicle are different.

The summarized weight target setting processes for new vehicle and carryover vehicle are shown in Figure 1.4 and Figure 1.5 below respectively.

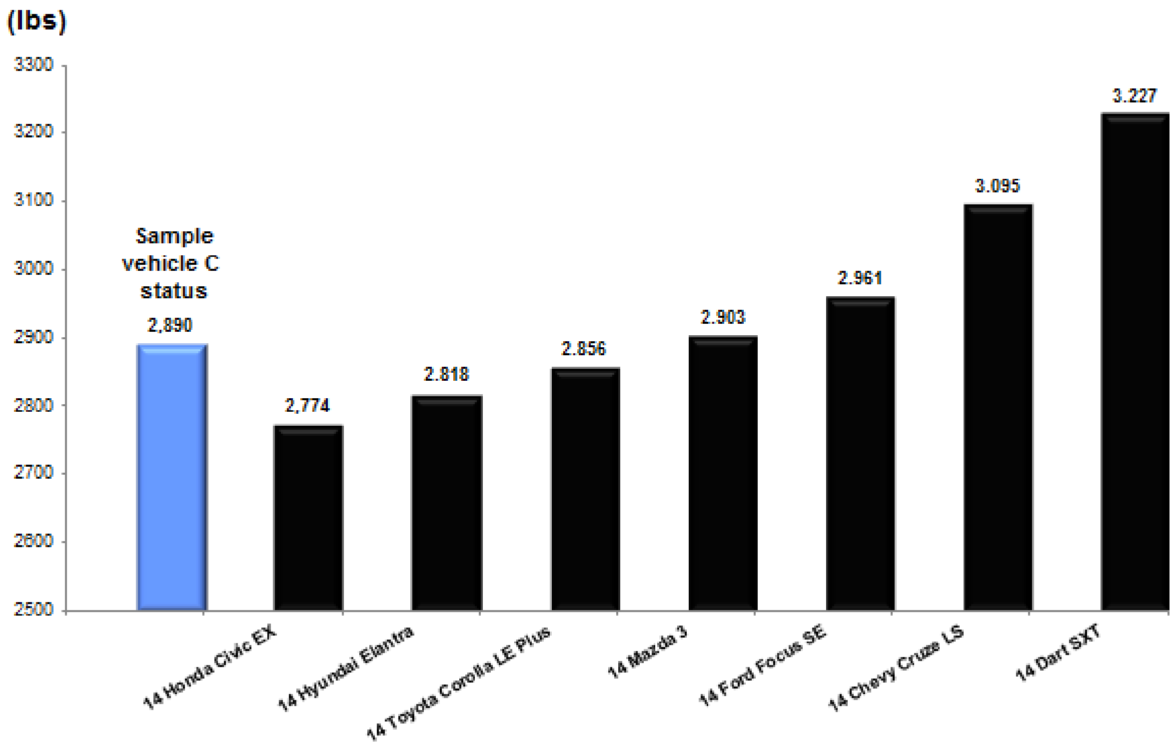


Figure 1.3, Example of absolute weight chart.

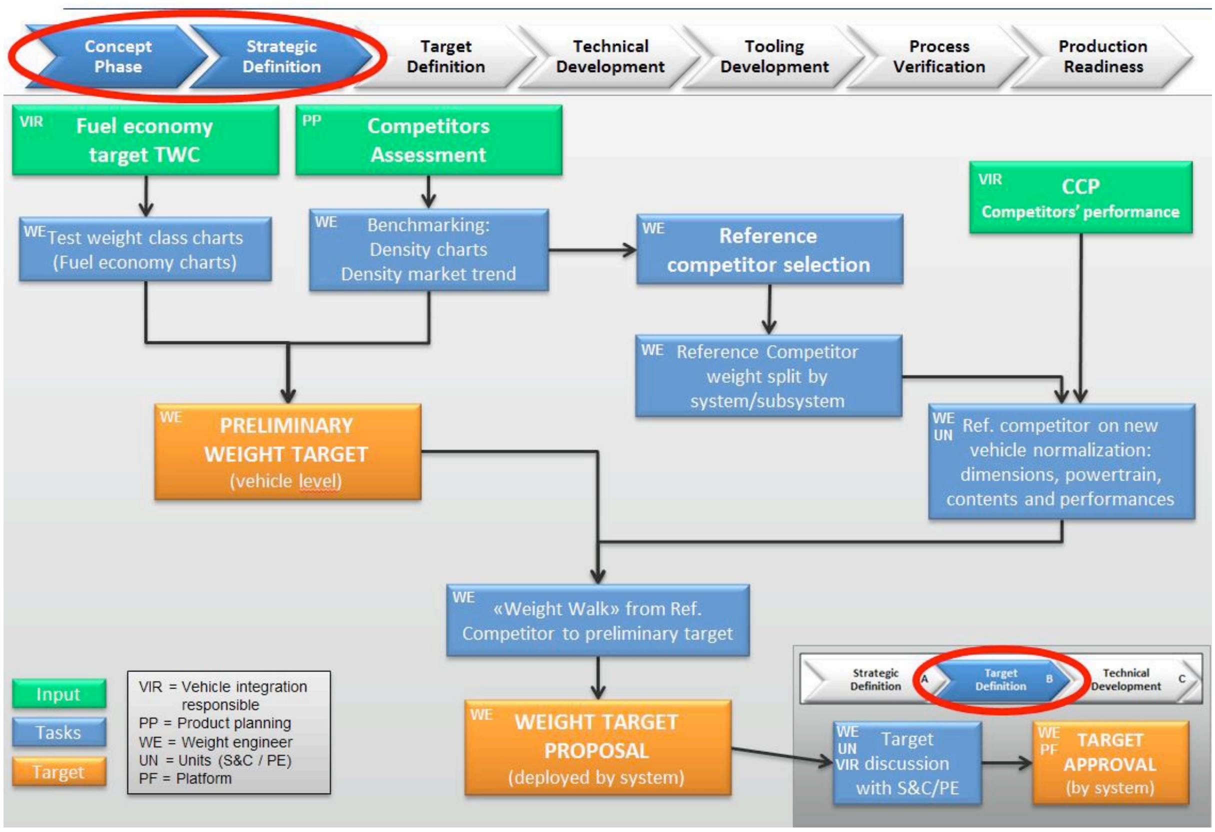


Figure 1.4, Target setting process for new vehicle.

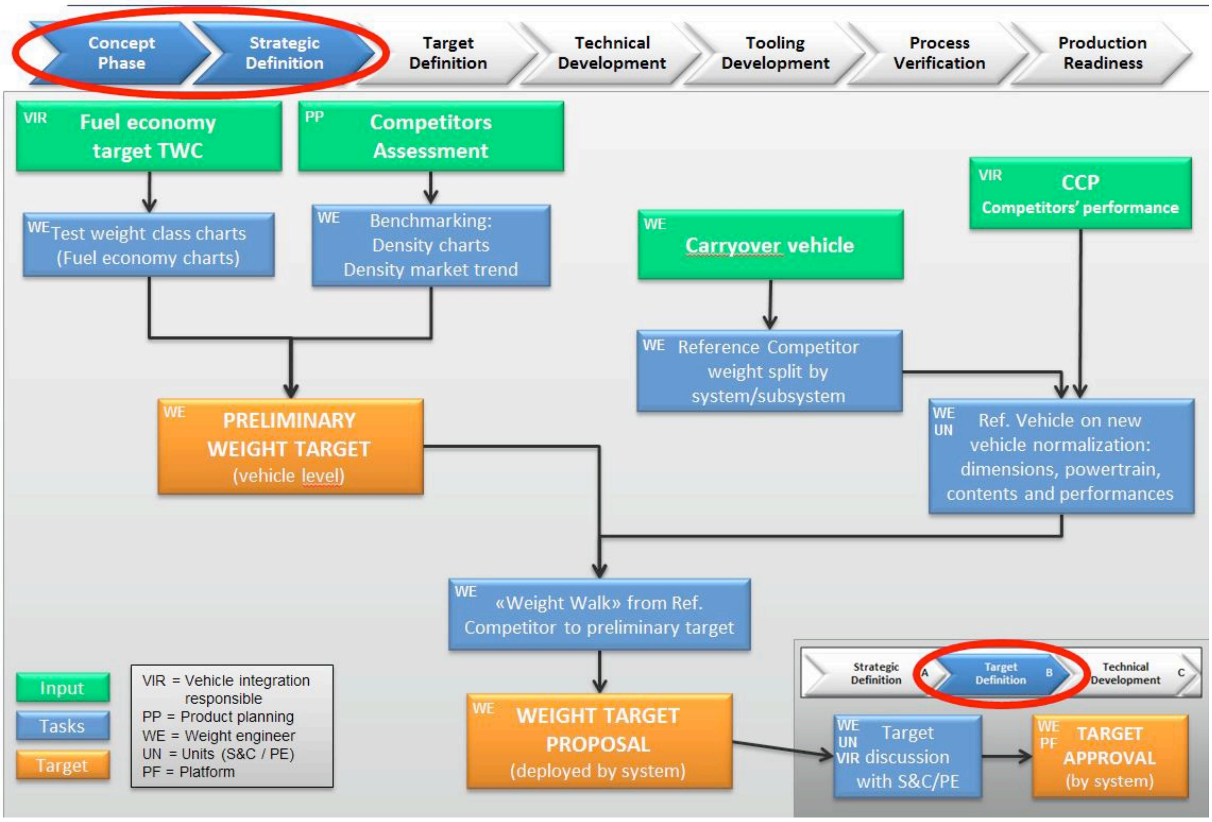


Figure 1.5, Target setting process for carryover vehicle.

Comparing the two processes listed above, the different between the target setting process for new vehicle and the one for carryover vehicle is the selection of the reference vehicle. In the process for the new vehicle, the reference vehicle, as a task, is based on the benchmarking activities. The exist old model is utilized as the reference vehicle for the carryover vehicle instead.

Some major steps will be described in the following briefly.

1.3.1 Test weight class charts (Fuel economy charts)

This step is the task which is under the guidance of the fuel economy target drawn by VIR. The purpose of the test weight class charts is to determine the feasibility to meet the test class. Test weight class charts plot the columns of possible targets to be assigned to every configuration (version) according to the fuel economy target provided by the VIR. The charts show the test weight class limits with contingencies. Typically, +2% for EMEA TWC limits, in order to keep a 1% contingency versus the regulatory limit and margin. An example is shown in Figure 1.6.

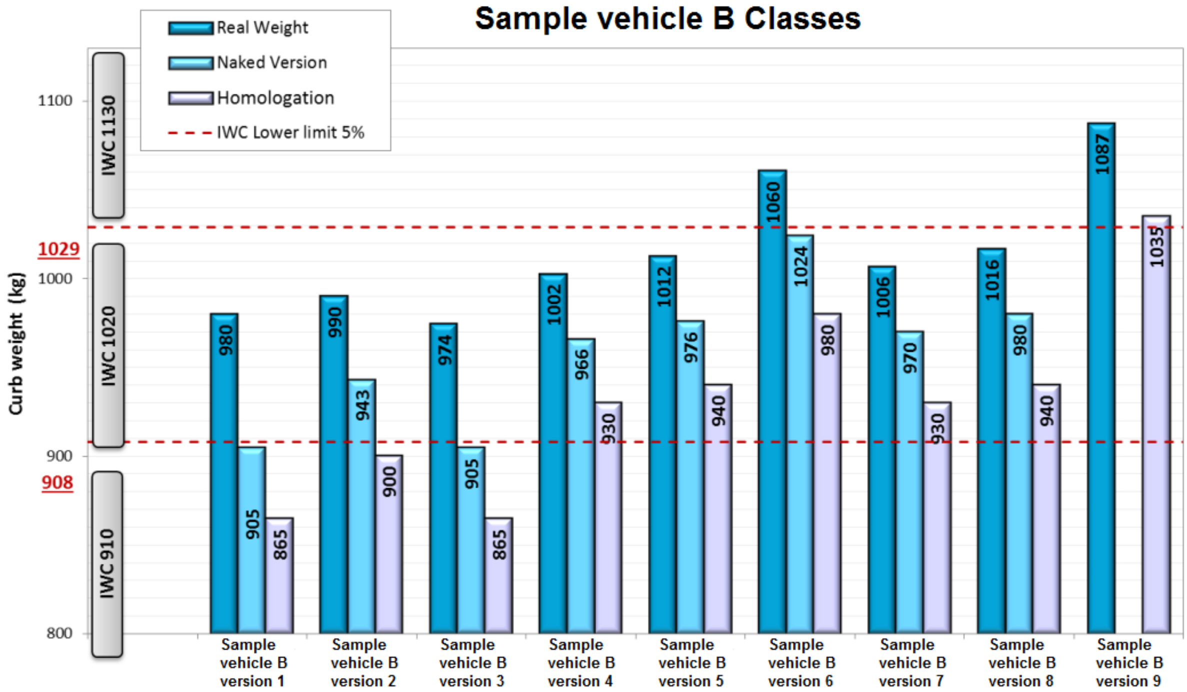


Figure 1.6, Example of test weight lass chart (for EMEA).

1.3.2 Preliminary vehicle targets

From Figure 1.4 and Figure 1.5, the preliminary vehicle target setting is driven by the mains factors that are the fuel economy plan and the target test weight classes and market competitiveness, for both new vehicle and carryover vehicle. In addition, for carryover vehicle, carryover components should be taken into account.

The test weight class charts (fuel economy charts) are used to determine the feasibility of the fuel economy target test weight class. Meanwhile, the density charts are used to evaluate the weight/volume efficiency of the competitors.

1.3.3 Reference competitor analysis

When the reference competitor is assured, the reference competitor weight is necessary to be analysed in detail in order to support the weight target proposal definition. The weight engineer should perform an analysis of the reference competitor. The analysis includes a detailed breakdown of the weight grouped according to the official FCA OSS systems and subsystems structure. This allows for an analysis of the reference competitor weight by system/subsystem.

The delta weight for every size, performance, dimension, powertrain contains should be evaluated by the weight engineer. The analysis should include an assessment of the quality performance. The targets are reviewed with the group System and Components.

1.3.4 Weight walk to target

A "weight walk to target" analysis could be represented in the form of graph and it is performed to establish the proposed weight target. The weight walk to target is developed based on the reference competitor (or exist vehicle) and delta weight. As a final step, weight reductions are investigated in order to achieve the preliminary weight target. An example of weight walk to target is shown in Figure 1.7.

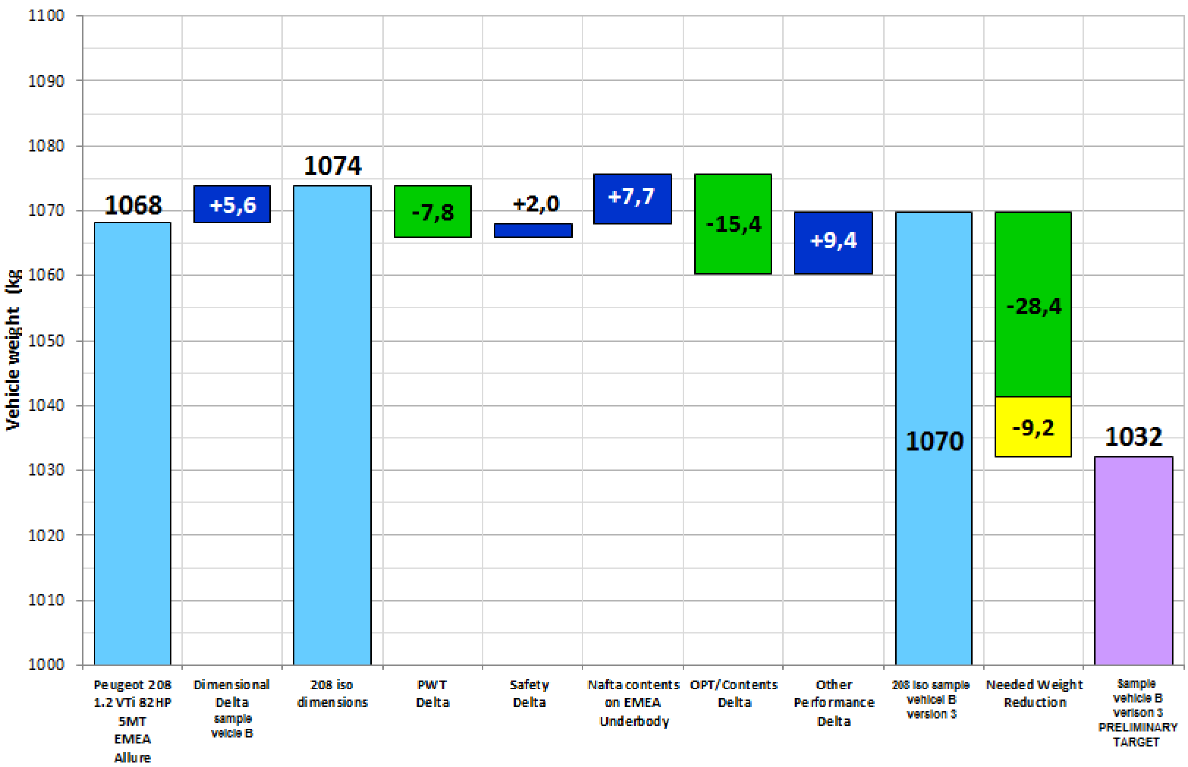


Figure 1.7, Example of weight walk to target.

1.3.5 Proposed target review and target approval

The competitive comparisons, of which the input is provided by the group Systems and Components, are used for target review. Target adjustments are made for valid reasons such as meeting fuel economy targets and to maintain competitiveness. Director approval is required for non-competitive target modifications. After the approval, the approved finalized weight targets are communicated in a bulletin.

1.4 Weight tracking

This step is not leaded by the weight engineer but the released and design engineer since the purpose of weight tracking is to provide feedback to the Model Responsible, VIR and the Platform for target status. It starts from the approved concept direction phase and continues to style approval phase of the development process.

For the weight engineer in this step, one of the main activities is to monitor the weight status of the project during the whole product development process. Beginning at the end of strategic definition phase, the weight engineer periodically obtains the weight status from the group System and Components for every subsystem.

As the programme proceeds, the accuracy of the weight status increases from estimations to actual production weights weighed components.

1.5 Weight reductions and risk management

The aim is to identify opportunities of weight savings and track weight increase risks through the weight management process. It is lasted through Job 1 and leaded by weight engineer with support from Project Responsible (PR).

Unallocated weight reduction task is distributed to functional areas bases on percentage of new part weight. Feasibility to achieve weight reduction is assessed based on risks and opportunities identified. Opportunities are established based on brainstorming, competitive analysis and technology improvements identified for each system. Risks are established which may negatively impact the functional area.

PRs provide status on risks and opportunities and define the weight impact, feasibility, timing, cost and application. An example of the document used to show the status of weight reduction is shown in Figure 1.8.

PROPOSAL				TIMING					CONFIDENCE					COSTS				STATUS	In Cost Service y/n
Owner (PR/PC)	Description	Notes	Weight Red. (kg)	OPENING DATE	FEASIBILITY DATE	PERFORMANCE DATE	CLOSING DATE	AVAILABLE FROM	FEASIBILITY	Performance	Brand	Style	Costs	Cost $	Estim. INVEST. BUY k€	Estim. INVEST. MAKE k$	R&D k€		
			TOT																
	Body:(-37)		0															-	
Bagley	•Closures	50%	(-12)	18/11/14	15/12/14				Y	Y								Y	
Bagley	•Body	30%	(-5)	18/11/14	15/12/14				R	R								R	
Bagley	•Side Steps	50%	(-5)	18/11/14	03/03/15				Y	Y								Y	
Bagley	•Front Bumper	50%	(-5)	18/11/14	03/03/15				Y	Y								Y	
Bagley	•Frt/Rear Wiper	50%, check BU	(-4)	18/11/14	01/02/15				Y	Y								Y	
Bagley	•Glass	risk,100%	2	18/11/14	15/12/14				G	G								G	
Bagley	•Wheel Liners	50%	(-2)	18/11/14	15/12/14				Y	Y								Y	

Figure 1.8, Example of weight reductions and risks template.

For every opportunity, it is necessary to include the weight, timing, confidence levels and costs/investments required for implementation.

1.6 Production audit

The weight engineer should confirm the weight of production vehicles with the support from the vehicle assembly plants. Actual production weights are required to comply with governmental regulations. The production audit starts at VP and continues throughout the life of the vehicle programme.

Production audit is accompanied with three phases of the production process:

- Process verification phase. Weight measurement required on 100% of VP pilot vehicles, to confirm the weight status;
- Production readiness phase. Weight measurement required on 50% of PS vehicles, to refine the weight status;
- After Job 1. Production weight will be measured on a minimum of 1% of vehicles. For EMEA, 1% audit of vehicles is recommended.

Vehicle must be at final production curb weight (including all components and fluids and without payload) prior to alignment. The equipment should measure the four corner weight.

The weight engineer is responsible to manage the audit information received by the plant, apply proper normalizations (if necessary), and create reports with statistical analysis i.e. average weight, standard deviation.

1.7 Homologation

The purpose is to specify the homologation process to meet the weight certification requirements for various markets including EMEA, Japan and Australia. The weight management process aligns to the timing specified by the homologation department between VP and Job 1. The homologated weight is utilized for estimating fuel consumption by NEDC and WLTP.

Weight engineer is responsible for completing a homologation template. There are unique requirements and templates for various regions.

A template contains the homologation weight (front/rear), GAWRs/GVWR (GAWR: gross axle weight rating, is the maximum allowable weight to be placed on the individual axle system, front or rear; GVWR: gross vehicle weight rating, is the maximum allowable vehicle weight, including driver, passengers, optional equipment, cargo, fuel, etc.) and max options weight (front/rear) along with the regulatory standards required for certification.

Moreover, a template utilized for EMEA also contains the weight of front and rear axle, with the considerations of combinations of the presence of driver and passengers, the weight of optional parts, the weight of towing hook, the weight of gross trailer and loaded trailer.

The homologated values could be found also in User Manuals. A page of the user manual of FIAT 500 is shown in Figure 1.9.

PESI

Pesi (kg)	0.9 TwinAir 60 CV* - 65 CV		0.9 TwinAir 80 CV* - 85 CV		0.9 TwinAir 105 CV	
	500	500C	500	500C	500	500C
Peso a vuoto (con tutti i liquidi, serbatoio combustibile riempito al 90% e senza optional):	865	905	930/940 ■	970/980 ■	940	980
Portata utile ● compreso il conducente:	475	445	440	415	440	415
Carichi massimi ammessi ▲ – assale anteriore: – assale posteriore: – totale:	 770 640 1340	 770 640 1350	 830 640 1370/1380 ■	 830 640 1385/1395 ■	 830 640 1380	 830 640 1395
Carichi trainabili a rimorchio frenato: rimorchio non frenato:	 800 400	 800 400	 800 400	 800 400	 800 400	 800 400
Carico massimo sulla sfera con rimorchio frenato:	60	60	60	60	60	60

● In presenza di equipaggiamenti speciali (tetto apribile, dispositivo traino rimorchio, ecc.) il peso a vuoto aumenta e conseguentemente diminuisce la portata utile, nel rispetto dei carichi massimi ammessi.

▲ Carichi da non superare. È responsabilità del conducente disporre le merci nel vano bagagli e/o sul piano di carico nel rispetto dei carichi massimi ammessi.

■ Versioni Dualogic.

* Per versioni/mercati, dove previsto

Figure 1.9, Page of weight of FIAT 500 user manual (Italian version).

CHAPTER 2

Weight versus Performance

2.1 Weight status of a vehicle

The purpose of the activity "weight versus performance" is to link certain performances of the vehicle with the corresponding systems/subsystems/components in order to evaluate the weight efficiencies of the considered performances of the vehicle for target setting. For weight versus performance, the aim is to make performances with a higher weight efficiency, i.e. higher performances with the as lower as possible corresponding weights. Not only the weight efficiency of the vehicle which is developing should be considered but also the competitors' vehicles in order to perform the benchmarking and the next steps of target setting.

Weight status of a developing vehicle and its systems/subsystems/components is significant for benchmarking. The weight status is the weight of a vehicle (or system/subsystem/component) at a particular timing during the development. Depending on the phase of the programme, the weight status of the components will have a different weight type i.e. design estimation, design actual weight and actual physical production weight. And the physical production part weight is considered the best weight type that the component confirms to the drawing itself. Periodically, the weight status should be compared to the corresponding target in order to confirm any deviation. During the development of a vehicle, the weight of a subsystem will consist of sum of the weight of each individual component. For each component, the best weight type must be considered to determine the most accurate weight status. A system weight status is the sum of all subsystems. The vehicle weight status is the sum of all systems.

Weight statuses of the developing vehicle and the competitors' vehicles should be concluded for benchmarking and analysing in detail. For a developing vehicle, its weight status is monitored in different developing phases. For a competitor's vehicle, the weight of the whole vehicle and of each system/subsystem/component are gathered from A2mac1. The weight status of each system/subsystem/component are organized according to the official FCA OSS structure in order to perform benchmarking with the developing vehicles. Since the weight data of competitors' vehicles are from A2mac1 AutoReverse teardown environment, the weight type of competitors' vehicles is the physical production part weight.

An example of a finished weight status report of competitor’s vehicle in implicit form is shown in Figure 2.1.

2	SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	Peugeot 3008 1.2 PureTech Allure 2016	
3					A2Mac1	Note
19			INTERIORS		194,4	
24			RESTRAINTS		15,9	
39			CHASSIS		328,0	
67			BODY		552,2	
85			ELECTRICS & ELECTRONICS		69,4	
95			ENGINE SYSTEMS		91,9	
110			POWERTRAIN		154,4	
111			**BASE CURB WEIGHT**		**1406,1**	
112			TOP-HAT	TH	555,2	
113			FLUIDS	F	51,3	
114			ARCHITECTURE	A	655,2	
115			POWERTRAIN	PWT	144,4	

Figure 2.1, Weight status report of Peugeot 3008.

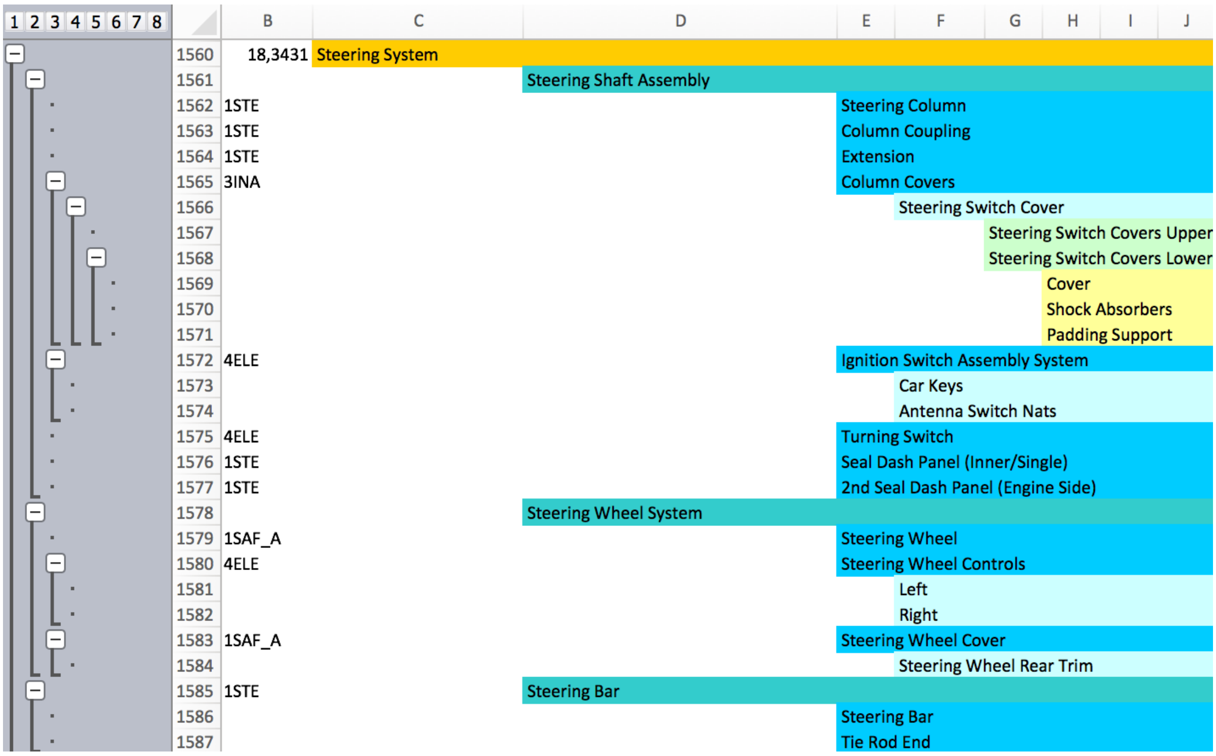
According to the official FCA OSS system, a vehicle consists of the systems of:

- Attached to INTERIORS: HVAC system, interiors, noise insulation;
- Attached to RESTRAINTS: restraints;
- Attached to CHASSIS: vehicle suspension, steering, pedal box;
- Attached to BODY: underbody & front end structure bumpers, body shell, body external accessories, door accessories, paints and sealers, mounting: assembly and parts undefined by the system;
- Attached to ELECTRICS & ELECTRONICS: informatics, electrics, energy, security, driving aid;
- Attached to ENGINE SYSTEM: fuel system, air induction, cooling system, exhaust;
- Attached to POWERTRAIN: engine, engine integration, gearbox, powertrain transmission & integration.

The base curb weight of a vehicle is the weight of the vehicle including all components and fluids and without any occupant, optional equipment and luggage.

The use of every part of a vehicle should be marked by its subsystem label in order to make a weight status report for a developing vehicle or a competitor's vehicle. Usually the name defined by FCA or A2mac1, shape, position and material of each part are checked and analysed for evaluating its use and ownership of subsystem.

For a competitor's vehicle of which the weight data is acquired from A2mac1 teardown environment, the weight status report could be made based on the bill of materials provided by A2mac1. An example is shown in Figure 2.2.



	B	C	D	E	F	G	H	I	J
1560	18,3431	Steering System							
1561			Steering Shaft Assembly						
1562	1STE			Steering Column					
1563	1STE			Column Coupling					
1564	1STE			Extension					
1565	3INA			Column Covers					
1566					Steering Switch Cover				
1567						Steering Switch Covers Upper			
1568						Steering Switch Covers Lower			
1569							Cover		
1570							Shock Absorbers		
1571							Padding Support		
1572	4ELE			Ignition Switch Assembly System					
1573					Car Keys				
1574					Antenna Switch Nats				
1575	4ELE			Turning Switch					
1576	1STE			Seal Dash Panel (Inner/Single)					
1577	1STE			2nd Seal Dash Panel (Engine Side)					
1578			Steering Wheel System						
1579	1SAF_A			Steering Wheel					
1580	4ELE			Steering Wheel Controls					
1581					Left				
1582					Right				
1583	1SAF_A			Steering Wheel Cover					
1584					Steering Wheel Rear Trim				
1585	1STE		Steering Bar						
1586				Steering Bar					
1587				Tie Rod End					

Figure 2.2, Label matching based on bill of materials.

Each part of the teardown should be labelled for the next analyses. For convenience, when some parts and/or several lower level subsystems have the same label, the label could be added for the higher level of subsystem which contains them and does not contain any other lower level subsystem and/or part with different labels. The numerical value of weight of each labelled row then is able to recorded and summed together.

The sum is equal to the base curb weight of the studied vehicle if there is no recording error, since the weight of a higher level subsystem consists of the weight of the lower level subsystems and independent parts which the higher level subsystem contains. For the labels, each of them represents one subsystem which is defined by FCA OSS system.

In Figure 2.2, for example, row 1580 is recorded as steering wheel controls and have the parts of left and right which are recorded by row 1581 and 1582 respectively. Since both left and right parts belong to the same kind of subsystem, which is electric/electronic commands and buttons, represented by the label “4ELE” defined by FCA OSS system, the label could be matched for the row 1580.

It is inconvenient to show all of the meanings of the labels in the thesis due to the confidentiality agreement.

2.2 Rules of the approach

In order to regulate the benchmarking activities during combining weights with performances for one or more vehicles, several rules should be obeyed. The rules described following come from the internal standard of FCA.

In practice, one subsystem may affect more than one performances of the vehicle. Starting from this point, the first rule is drawn: if two or more performances are affected by the same subsystem, the contributions of the weight of the subsystem for different performances must be weighted in a reasonable way. Here it can use an example to explain more. Bonnet inner frame has a medium impact to high speed front crash and a high impact to low speed front crash. If a vehicle has a bonnet inner frame with the weight of 3.5 kg, the total weight could be split into 1.2 kg and 2.3 kg for accounting the weight contributions to high speed front crash and low speed front crash respectively.

The second rule is that, weight contributions to performances of subsystems must be updated by occurrence when one or more performances are taken into account. Therefore, it can be concluded that, combining with the first rule, the weight status of a vehicle must be the same both in the forms of systems/subsystems/components and contributions of performances.

To fulfil the conclusion mentioned in last paragraph, it is reasonable to create an additional kind of performances called “other” in order to link the weights of the components which does not have any contribution to the considered performances. This is the main contains of the third rule.

The fourth rule indicates that the transformation law between weights and parameters should be defined in a way that obeys “higher is better” logic, for comparing the efficiencies of the subsystems between different vehicles in radar graph representation in a convenient way. Finally, a measure of hole weight efficiency of a vehicle is given by the geometric mean of the values of points on the radar graph.

2.3 Performances and their representations

Several main performances of a vehicle are taken into account for benchmarking for weight management. For a conventional car, usually the considered performances are:

- Safety performances, including front high speed crash, front low speed crash, rear high speed crash, rear low speed crash and side high speed crash;
- HVAC performance;
- Aerodynamic performance;
- Powertrain performance;
- NVH performance.

For a BEV, the performances above are also taken into account and, in addition, the autonomy performance, which describes the range covered by the vehicle after charging. In this chapter the autonomy performance of BEV will be skipped. It will be described deeply in chapter 3.

In order to perform analysis of performances, it is necessary to quantize the performances by their corresponded parameters. Inside FCA, quantizing activity should be assisted by other departments, i.e. Safety, Aerothermal, Powertrain and NVH, for acquiring the parameters needed for analyses in the different phases of development. Not only the developing vehicles' parameters should be tracked but also the competitors' should be gathered from several sources.

The parameters which are necessary to be acquired are:

- Euro NCAP ratings, include adult occupant protection in frontal impact rating, adult occupant protection in side impact rating, total adult occupant rating (both points and percentage), pedestrian rating (in percentage), for safety performances;
- Dimensions, SAE standard, for safety performances and HVAC performance;
- Drag area, which is drag coefficient multiplied by frontal area, for aerodynamic performance;
- Horse power, for powertrain performance;

- Acceleration time from 0 to 100 km/h in seconds, for powertrain performance;
- Customer Care Profiles (CCP), which are internal subjective ratings evaluated and utilized inside FCA, of HVAC and NVH performances.

The parameters should come from reliable sources, such as:

- For Euro NCAP ratings: Euro NCAP official website;
- For dimensions: A2mac1, Dimensional Portfolio documents (official FCA EMEA source);
- For drag area: data from Aerothermal department and reliable websites;
- For horse power and acceleration time: official announcements of competitors;

The performances should be represented in a numerical form by their corresponded parameters, in order to perform comparisons between different vehicles. The numbers which represent performances are called coefficients. For the performances mentioned above, except the autonomy performance which will be described in detail in chapter 3, the coefficients are calculated in a suitable way in order to evaluate the performances. In this chapter the calculation method of the coefficients described in Table 2.1 is an old version used inside FCA.

Where in Table 2.1, the definition of dimensions is based on the SAE standard. The three dimensional reference system defined by SAE is shown in Figure 2.3. The most significant dimensions are W103, W117 and W20-1. W103 is the maximum vehicle width which represents the maximum lateral distance between the widest points on the vehicle, including all trim and hardware except the mirrors [1]. SgRP is a specific and unique H-point established by the manufacturer as the design seat reference point for a given designated seating position [1]. W117 is front body width at seating reference point SgRP, which means the maximum lateral distance between the natural shape of the vehicle through the SgRP-Front X-plane, excluding door handles, running boards, door protection moldings, or any local protrusion [1]. W20-1 represents SgRP Y coordinate for the driver [1]. Moreover, L101 is the wheel base, H100 is the maximum distance on the body in white normal to ground exclude all hardware and trim. The locations of the relevant dimensions are shown in Figure 2.3-2.5.

Performance	Coefficient
Front high speed crash	(Euro NCAP adult occupant protection in frontal impact rating ⁄ Full marks of Euro NCAP adult occupant rating of the published year) ⁄ W103
Front low speed crash	Euro NACP pedestrian rating · W103
Rear high speed crash	1 ⁄ W103
Rear low speed crash	1 ⁄ W103
Side crash	(Euro NCAP adult occupant protection in side impact rating ⁄ Full marks of Euro NACP adult occupant rating of the published year) ⁄ (W117 ⁄ 2 – W20-1)
HVAC	HVAC CCP · Roominess index
Aerodynamic	1 ⁄ (Drag coefficient · Frontal area)
Powertrain	Weight to power ratio ⁄ Acceleration time from 0 to 100 km/h in seconds
NVH	NVH CCP
Other	L101 · W103 · (H100 – Clearance to ground)

Table 2.1, Performances and corresponded coefficients.

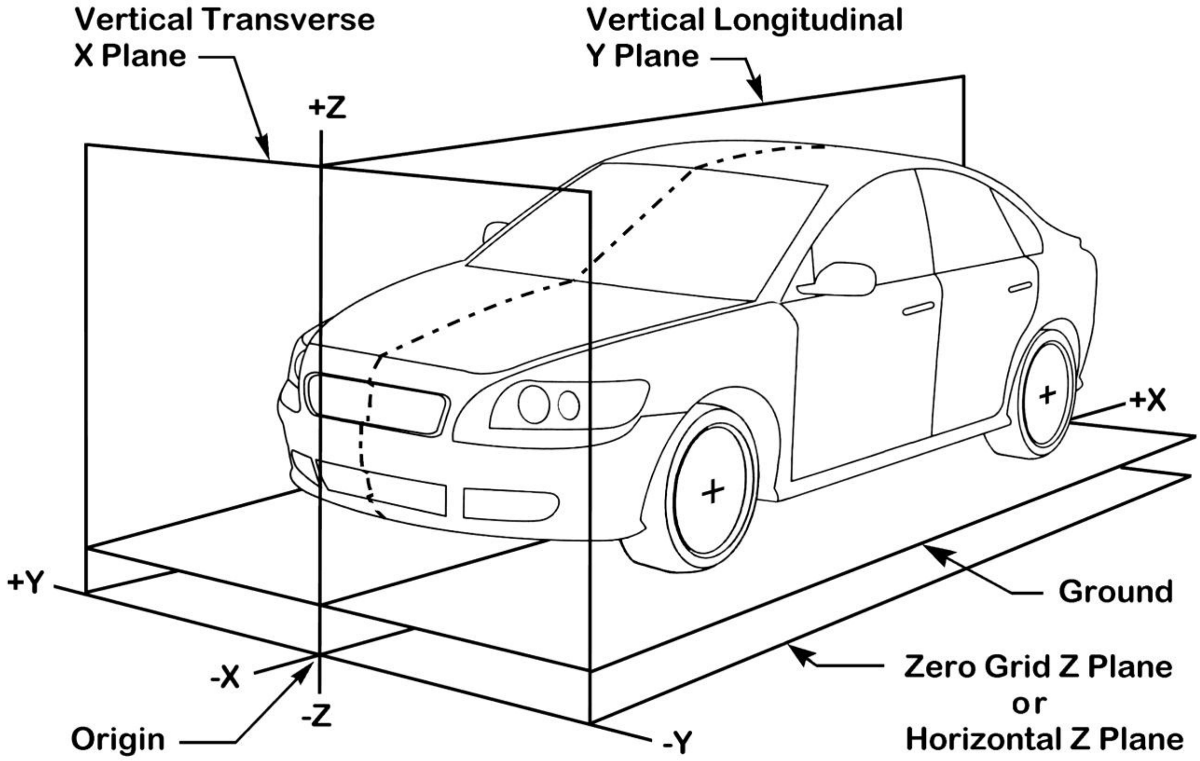


Figure 2.3, SAE defined three-dimensional system [1].

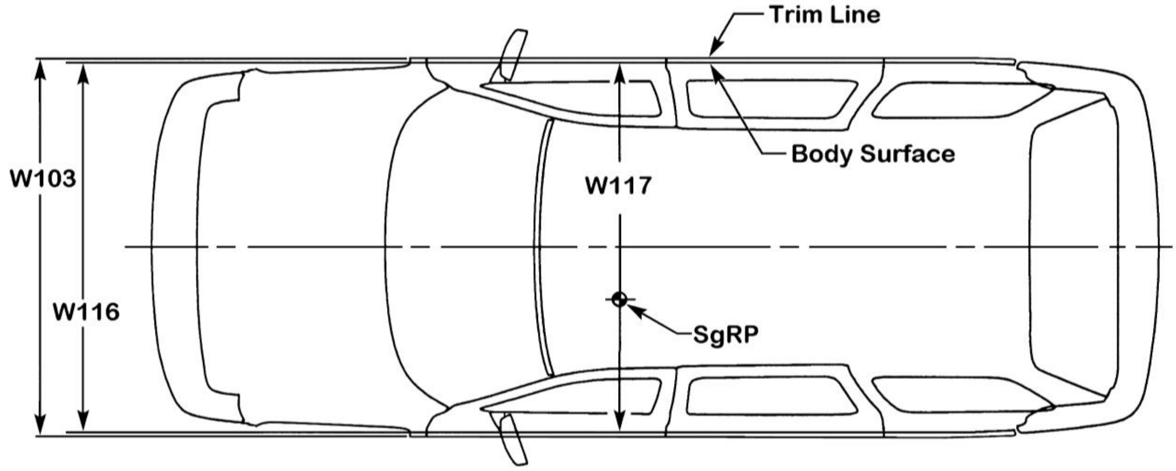


Figure 2.4, SAE standard vehicle widths [1].

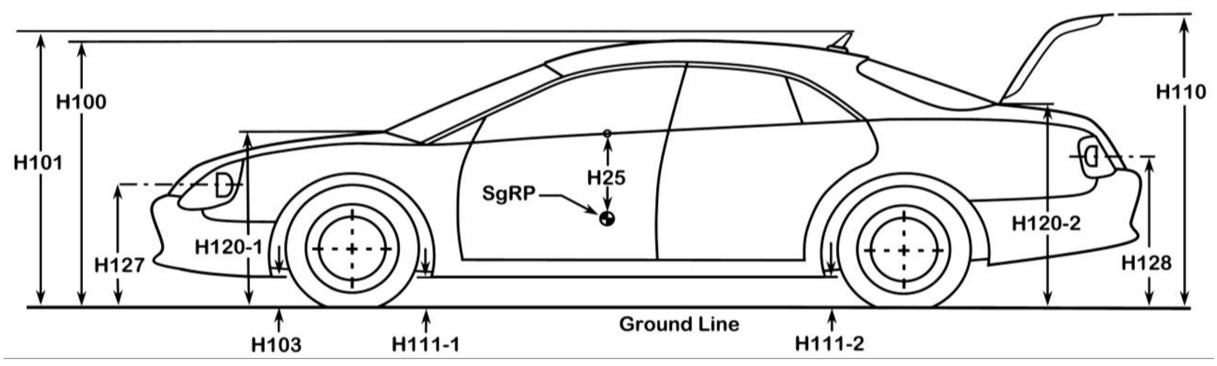


Figure 2.5, SAE standard vehicle exterior height [1].

Roominess index is an index which describes the cabin room of a vehicle by combining several internal dimensions of the vehicle and it is an internal standard inside FCA. In order to introduce the internal dimensions which are involved into the calculation of roominess index, some additional definitions should be introduced.

The use of H-Point Machine (HPM-II) is mandatory to define and measure the following definitions of dimensions in SAE J1100 document. The point in the lateral centre plane of the shoe tool at the bottom rear of the shoe heel is defined as heel of shoe (HOS) [1]. When HOS is properly positioned on the depressed floor covering, it defines the location of accelerator heel point (AHP) for the driver and floor reference point (FRP) for passengers [1]. The point on the lateral centreline of the shoe 203 mm from HOS is defined as ball of foot (BOF) [1]. BOFRP is the ball of foot reference point, which is a vehicle reference point coincident with the driver's BOF location when: the flat portion of the bottom of shoe is coplanar with the driver's shoe plane; the driver's heel of shoe is on the driver's depressed floor covering; the BOF lies on the accelerator pedal centreline when the centreline is projected to the shoe plane [1]. These points defined above are shown visually in Figure 2.6.

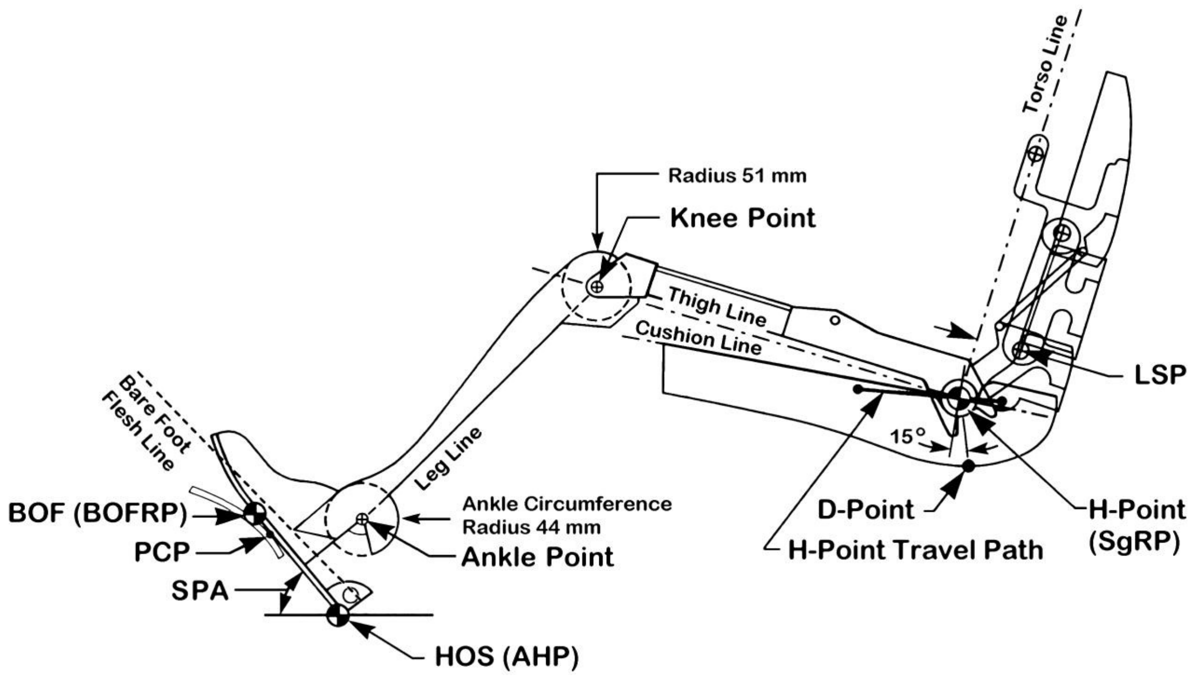


Figure 2.6, Visual representation of the points by using HPM-II [1].

For passenger rows, the plane normal to the Y-Plane, established by the bottom of shoe contacting the floor, with the heel of shoe on the depressed floor covering at the floor reference point is called floor plane. The floor plane angle (FPA) is the angle of the floor plane measured from the horizontal [1].

Roominess index involves the dimensions of L99-1, L51-2, H30-1, H30-2, H61-1, H61-2, W3-1, W3-2 to describe the space of the cabin in a quantitative form. The definitions of these dimensions are given in the Table 2.2. The visual representations are shown in Figure 2.7-2.10.

Code	Dimension	Definition
L99-1	Driver's BOF to SgRP – Front	The longitudinal distance (horizontal to grid) between the driver's BOF and driver's SgRP.
L51-2	Effective Leg Room (Passengers)	The planar distance as measured on a Y-plane from the ankle point to the SgRP, plus 254 mm, with the heel of the shoe at the FRP and the bottom of the shoe oriented at the FPA for the second row outboard passenger.
H30-1	Seat Height – Front	The vertical distance from SgRP to AHP. Measure with floor mats if they are standard equipment.
H30-2	Seat Height – Second	The vertical distance from SgRP to FRP of the second row. Measure with floor mats if they are standard equipment.
H61-1	Effective Head Room – Front	The distance along a line 8 degrees rear of vertical from the SgRP to the first limiting surface (headlining, molding, sunroof shade, etc.), plus 102 mm, for the first row.
H61-2	Effective Head Room – Second	The distance along a line 8 degrees rear of vertical from the SgRP to the first limiting surface (headlining, molding, sunroof shade, etc.), plus 102 mm., for the second row.
W3-1	Shoulder Room – Front	The minimum lateral distance between the trimmed door or quarter trim surfaces within the measurement zone, for the first row. The zone lies between the beltline and 254 mm above SgRP, on the X-plane through SgRP. The door assist strap is excluded.
W3-2	Shoulder Room – Second	The same with W3-1, but for the second row.

Table 2.2, Definitions of the dimensions needed for calculating roominess index [1].

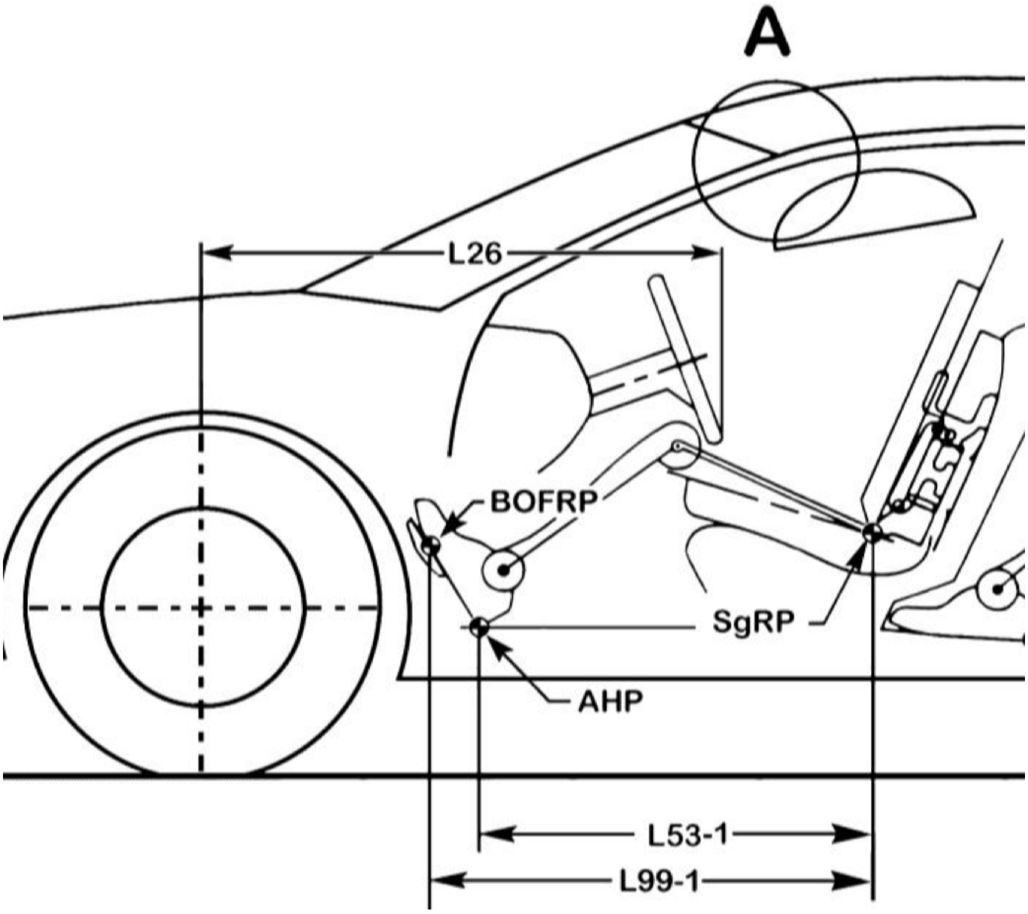


Figure 2.7, Visual representation of L99-1 and other dimensions and points [1].

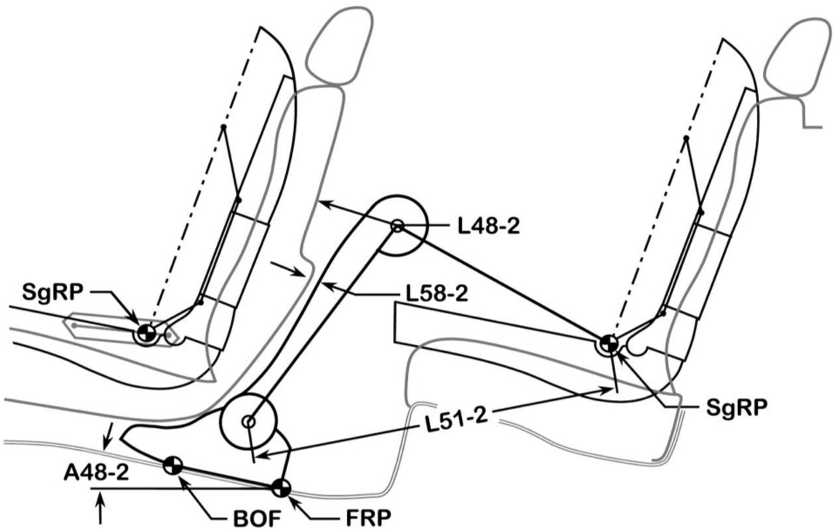


Figure 2.8, Visual representation of L51-2 and other dimensions and points [1].

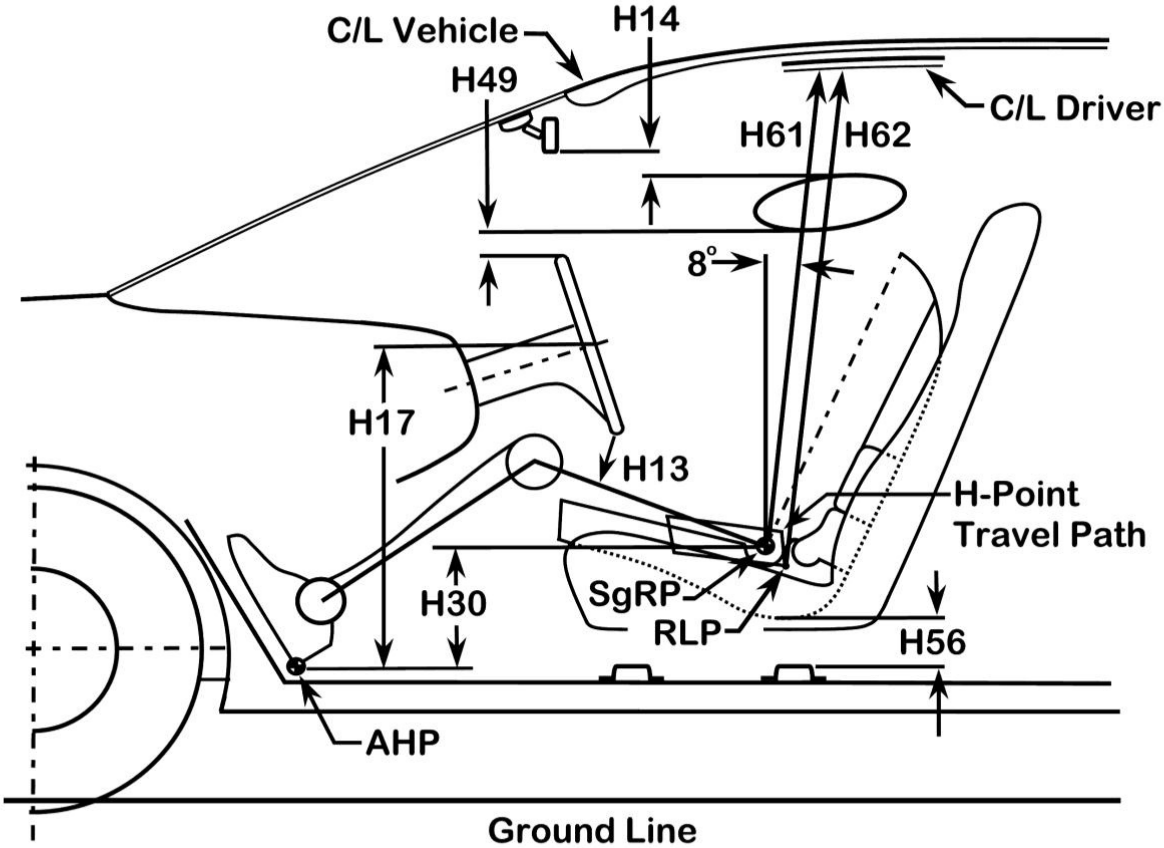


Figure 2.9, Visual representation of H30 and H61 and other dimensions and points, at driver's position [1].

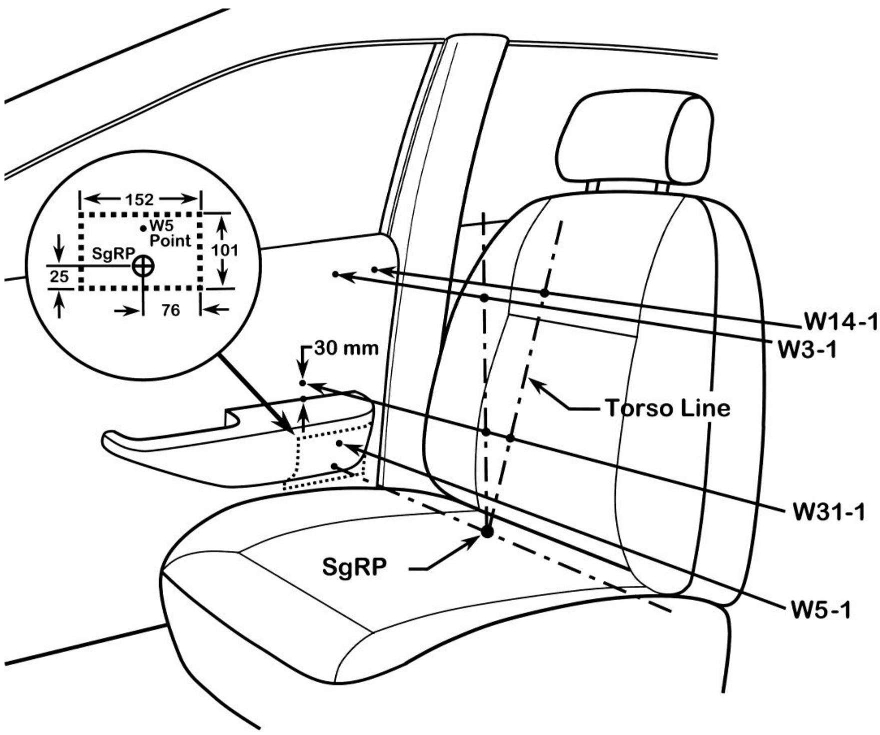


Figure 2.10, Visual representation of W3-1 and other dimensions, lines and points, at driver's position [1].

Since the Euro NCAP adult occupant rating might be alternated for different year of publication, it is convenient to use the ratio between the detailed rating needed for analysing and the total adult rating of the published year to estimate the absolute performance of the considered rating (frontal impact or lateral impact in the thesis). The full marks of Euro NCAP adult occupant rating of the published year is calculated as the ratio between the total adult occupant rating of a model tested in the published year and the percentage of the points gained by that model. For example, the estimated full marks of Euro NCAP adult occupant rating of 2012 is calculated as the ratio between 31.9 and 89% in Figure 2.11, and the estimated full marks of the year 2015 is calculated as the ratio between 32.7 and 85% in Figure 2.12.

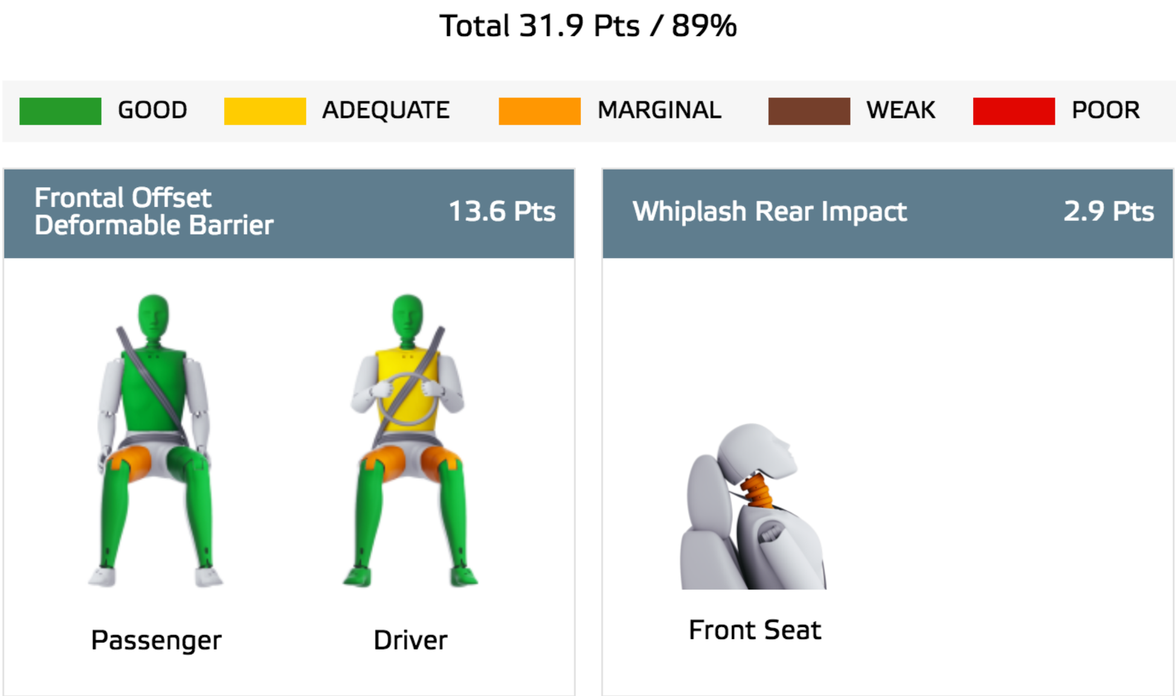


Figure 2.11, Rating, percentage and partial detailed points of Nissan Leaf tested in 2012 [2].

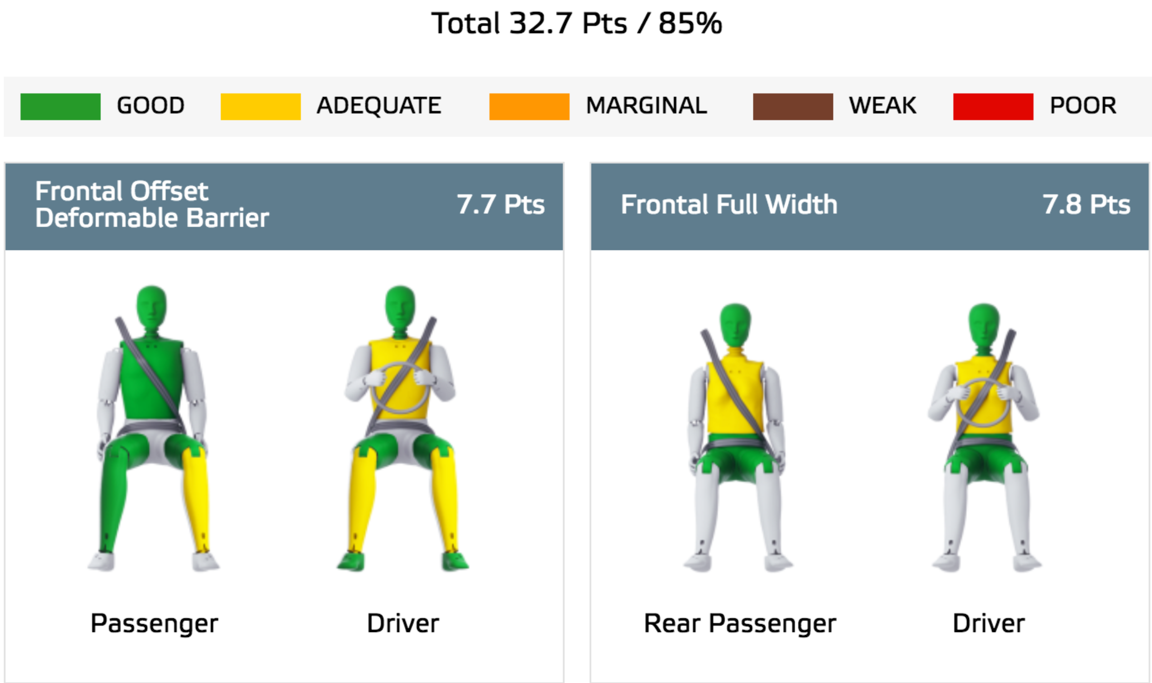


Figure 2.12, Rating, percentage and partial detailed points of Hyundai i20 tested in 2015 [3].

During the year 2015, Euro NCAP changed the evaluating method for adult protection in front impact: frontal offset deformable impact was not the only method but also the front full width impact. Although the method changed, the total rating for adult front impact protection remained constant and became that frontal offset deformable impact occupies one half of the rating and front full width impact occupies another half. Therefore, for the models which are tested before 2015, the adult occupant protection in frontal impact rating is considered as the the frontal offset deformable barrier points; for the models which are tested in and after 2015, the adult occupant protection in frontal impact rating is considered as the sum of frontal offset deformable barrier points and frontal full width points.

It is better to use the Euro NCAP results of the model of which the model year is the same with the studied model. If it is not possible, the Euro NCAP results of the old version of the studied model are allowable if the studied model is structurally identical to its old version which has a Euro NCAP rating.

2.4 Linking weight with performance

2.4.1 Main components contribute to the considered performances

Next some main components contribute to the considered performances will be listed briefly.

2.4.1.1 Main components contribute to high speed front crash

For the body, front cross beam system and front longitudinal rails have high impact to the performance of high speed front crash obviously. And also the side sills, of both under body and upper body, and the whole A-pillars and the upper beams of the driver and passenger doors give a high contribution. The front floor and the bonnet inner frame have a medium impact.

Chassis also affects the performance of high speed front crash, especially the sub frame of front suspension and the steering column which have medium impact and high impact respectively.

Restraint systems, seats frame, dashboard and dashboard structure have a high impact to the protection when high speed front crash occurs. Therefore, their weights are necessary to be considered when considering the performance of high speed front crash.

2.4.1.2 Main components contribute to low speed front crash

The whole bumper of a vehicle plays a significant role in low speed front crash and also the bonnet inner frame. Since the performance of low speed front crash focuses mainly on pedestrian protection, the components of body structure are rarely considered except the front cross beam system. In addition, windscreen has a medium impact to the pedestrian protection.

2.4.1.3 Main components contribute to high speed rear crash

As the energy absorbing and anti-crash components, rear bumper cross beam, crash box and rear longitudinal rails give high impact to rear high speed crash. In addition, rear trunk floor has medium contribution to resisting rear high speed crash. The whole rear suspension system has a medium contribution and rear wheels have a high contribution to high speed rear crash performance.

Similar with their functions during high speed front crash, seat frames for each row affect occupants protection deeply especially for anti-whiplash when high speed rear protection occurs so that they must be taken into consideration.

2.4.1.4 Main components contribute to low speed rear crash

The rear longitudinal rails also give high contribution to the performance of low speed rear crash. And similar with the importance in low speed front crash, rear bumper is significant when we talk about rear low speed crash.

The components of seats which are produced according to just-in-time methodology are considered important since shocks can be absorbed and reduced by them during low speed crash therefore good for occupant protection.

2.4.1.5 Main components contribute to high speed side crash

The sills and the whole body side should be taken into consideration obviously. Moreover, doors and their latches are significant. For the whole seats, frames have higher impacts than just-in-time components. Also the internal trims and restraints cannot be ignored.

2.4.1.6 Main components contribute to HVAC comfort

The whole HVAC module has high impact to HVAC comfort without any additional description also the air ducts inside dashboard and air vents which are attached to dashboard. On bumper, grille plays an important role, which is always missed by people, to the inner climate comfort.

2.4.1.7 Main components contribute to aerodynamics

External trims affect aerodynamic performance deeply, especially the front air dams, side air curtains, underbody shields and rear spoiler or wing.

2.4.1.8 Main components contribute to powertrain performance

Engine and its accessories, gearbox, transmissions and differentials are the powertrain components. Naturally their performances consist the performance of the whole powertrain.

2.4.2 Representing weight status in performance form

The weight statuses of studied vehicles should be listed at the same time for comparing intuitively. In this chapter and chapter 3, Renault ZOE ZE Intens 2013 and Nissan Leaf SV 2017 are utilized as studied models. Figure 2.13 shows the weight statuses of the two vehicles.

	SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017
14					A2mac1	A2mac1
15						
31	INTERIORS				142,0	158,5
36	RESTRAINTS				13,9	19,5
51	CHASSIS				274,0	322,5
79	BODY				545,9	532,7
97	ELECTRICS & ELECTRONICS				41,5	52,4
107	ENGINE SYSTEMS				15,0	14,2
122	POWERTRAIN				432,9	426,5
123	BASE CURB WEIGHT				1465,2	1526,2

Figure 2.13, Weight statuses of Renault ZOE ZE Intens 2013 and Nissan Leaf SV 2017.

The weight status of each subsystem for the studied vehicles, which is organized according to FCA OSS structure, should be weighted based on the contribution of the corresponded subsystem to the considered performances. The contributions of the subsystems are represented by numbers and managed carefully. The examples of weight statues of the subsystems and the contributions of the subsystems are shown in Figure 2.14 and Figure 2.15 respectively. In Figure 2.15, the absolute value of a cell is linked directly with the importance of the corresponded subsystem for the corresponded performance. The positive values of a subsystem for all performances are summed together and then put in the last column as total contribution to all performances. If a subsystem with the sum of contribution values not greater than 1 for all of the performances except "other", the contribution of this subsystem to "other" will be set to the value which makes the total contribution to 1. The negative values of a subsystem are not taken into account to the value of total contribution. They are only for indicating that, this subsystem has no contribution to the corresponded performance but without it the corresponded performance will be better.

The weight of a subsystem will be split and distributed to the relative performances, according to the ratio of each corresponded positive contribution in the total contribution value, for evaluating efficiency in the next steps of analysis. An example is shown in Figure 2.16.

Also the weights of some specific subsystems/components, especially the teardown of BIW, are attached to the subsystem sorted according to FCA OSS structure, should be analysed separately and split from the weight of their corresponded subsystem sorted according to FCA OSS structure to maintain the weight balance in the form of performance. Figure 2.17, Figure 2.18, Figure 2.19 show the examples of weight statuses, contributions and split weight distributed to performances.

Since the whole work sheet is too large and the work sheet is protected by the confidentiality agreement, only the parts relevant to the system "INTERIOR" of the sheet are shown are the form of screenshot in the thesis. It is not convenient to describe the work sheet exhaustively.

13	SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017
14					A2mac1	A2mac1
15						
16	CLI	1CLI	HVAC	A_CORE	10,0	11,6
17		2CLI	CLIMATE CONTROLS	TH	0,0	0,3
18		3CLI	AIR CONDITIONING SYSTEM	A_CONT	16,5	13,0
19	INA	1INA_FF	SEATS (FRONT frame)	A_CORE	21,2	28,6
20		1INA_RF	SEATS (REAR frame)	A_CONT	9,7	17,0
21		1INA_FJ	SEATS (FRONT Jit)	TH	10,3	8,0
22		1INA_RJ	SEATS (REAR Jit)	TH	7,6	10,5
23		2INA	IP CROSS BEAM	A_CORE	9,6	11,1
24		3INA	DASHBOARD AND CONSOLE	TH	17,3	17,0
25		4INA	INNER TRIM	TH	12,7	16,0
26		5INA	SIDE DOOR - TRIM	TH	12,3	11,0
27		6INA	INTERNAL ILLUMINATION	TH	0,0	0,1
28	INS	1INS	INSULATION	TH	14,9	14,3
29	INTERIORS Top-Hat			TH	75,1	77,2
30	INTERIORS Architecture			A	66,9	81,3
31	INTERIORS				142,0	158,5

Figure 2.14, Weight statuses of subsystems of interiors.

	SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	SAFETY					HVAC	AERO	PWT	AUT	NVH	OTHERS	TOT
14					Front HS	Front LS	Rear HS	Rear LS	Side HS							
16	CLI	1CLI	HVAC	A_CORE	1,00					1,00				0,19	0,00	2,19
17		2CLI	CLIMATE CONTROLS	TH	0,00					1,00				0,00	0,00	1,00
18		3CLI	AIR CONDITIONING SYSTEM	A_CONT	-0,50					1,00				0,36	0,00	1,36
19	INA	1INA_FF	SEATS (FRONT frame)	A_CORE	1,00		1,00		1,00					0,11	0,00	3,11
20		1INA_RF	SEATS (REAR frame)	A_CONT	1,00		1,00		1,00					0,11	0,00	3,11
21		1INA_FJ	SEATS (FRONT Jit)	TH				1,00	0,50					0,11	0,00	1,61
22		1INA_RJ	SEATS (REAR Jit)	TH				1,00	0,50					0,11	0,00	1,61
23		2INA	IP CROSS BEAM	A_CORE	1,00				0,50					0,28	0,00	1,78
24		3INA	DASHBOARD AND CONSOLE	TH	1,00		-1,00							0,06	0,00	1,06
25		4INA	INNER TRIM	TH	0,50				1,00					0,00	0,00	1,50
26		5INA	SIDE DOOR - TRIM	TH					1,00					0,00	0,00	1,00
27		6INA	INTERNAL ILLUMINATION	TH					-0,50					0,00	1,00	1,00
28	INS	1INS	INSULATION	TH										0,53	0,47	1,00
29	INTERIORS Top-Hat			TH											1,00	1,00
30	INTERIORS Architecture			A											1,00	1,00
31	INTERIORS														1,00	1,00

Figure 2.15, Contributions of the subsystems.

	SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017
14					SIDE HIGH SPEED		HVAC		AERO		PWT		NVH	
16	CLI	1CLI	HVAC	A_CORE	0,0	0,0	4,6	5,3	0,0	0,0	0,0	0,0	0,9	1,0
17		2CLI	CLIMATE CONTROLS	TH	0,0	0,0	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0
18		3CLI	AIR CONDITIONING SYSTEM	A_CONT	0,0	0,0	12,1	9,5	0,0	0,0	0,0	0,0	4,4	3,4
19	INA	1INA_FF	SEATS (FRONT frame)	A_CORE	6,8	9,1	0,0	0,0	0,0	0,0	0,0	0,0	0,8	1,0
20		1INA_RF	SEATS (REAR frame)	A_CONT	3,1	5,5	0,0	0,0	0,0	0,0	0,0	0,0	0,3	0,6
21		1INA_FJ	SEATS (FRONT Jit)	TH	3,2	2,5	0,0	0,0	0,0	0,0	0,0	0,0	0,7	0,6
22		1INA_RJ	SEATS (REAR Jit)	TH	2,4	3,2	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,7
23		2INA	IP CROSS BEAM	A_CORE	2,7	3,1	0,0	0,0	0,0	0,0	0,0	0,0	1,5	1,7
24		3INA	DASHBOARD AND CONSOLE	TH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,9	0,8
25		4INA	INNER TRIM	TH	8,5	10,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
26		5INA	SIDE DOOR - TRIM	TH	12,3	11,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
27		6INA	INTERNAL ILLUMINATION	TH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28	INS	1INS	INSULATION	TH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	4,7	2,3
29	INTERIORS Top-Hat			TH										
30	INTERIORS Architecture			A										
31	INTERIORS													

Figure 2.16, Split weights contribute to performances.

	SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017
14					A2mac1	A2mac1
131		1INA_FF	Heated front seats		0	0,27
132		3INA	Air duct		0,5	1,041
133		3INA	Grill		0,334	0,938
134		1INS	Under Engine Shield		0	0,155
135		1INS	Complete carpet + foot rest support		5,863	9,764

Figure 2.17, Weight statuses of specific subsystems/components needed to be analysed separately.

SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	SAFETY					HVAC	AERO	PWT	AUT	NVH	OTHERS	TOT
				Front HS	Front LS	Rear HS	Rear LS	Side HS							
	1INA_FF	Heated front seats		1,00		1,00		1,00	1,00				0,11	0,00	4,11
	3INA	Air duct		1,00		-1,00			1,00				0,06	0,00	2,06
	3INA	Grill		1,00		-1,00			1,00				0,06	0,00	2,06
	1INS	Under Engine Shield								1,00				0,00	1,00
	1INS	Complete carpet + foot rest support		0,50									0,53	0,00	1,03

Figure 2.18 Contributions of specific subsystems/components needed to be analysed separately.

	SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017
13														
14					SIDE HIGH SPEED		HVAC		AERO		PWT		NVH	
15														
131		1INA_FF	Heated front seats		0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
132		3INA	Air duct		0,0	0,0	0,2	0,5	0,0	0,0	0,0	0,0	0,0	0,0
133		3INA	Grill		0,0	0,0	0,2	0,5	0,0	0,0	0,0	0,0	0,0	0,0
134		1INS	Under Engine Shield		0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,0
135		1INS	Complete carpet + foot rest support		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	3,0	5,0

Figure 2.19, Split weights of specific subsystems/components needed to be analysed separately distributed to performances.

	WEIGHT	
	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017
Front HS	191,3	190,8
Front LS	50,7	48,4
Rear HS	88,4	100,6
Rear LS	34,6	33,6
Side HS	106,8	109,1
HVAC	18,8	18,5
AERO	16,4	20,5
PWT	181,1	157,9
AUT	270,4	287,6
NVH	163,9	160,7
OTHER	343,0	398,7
TOT	1465,2	1526,2

Figure 2.20, Weight statuses represented in performance form.

The sum of weights contributes to all of the performances include "other", or described by another phrase, vehicle's weight status in the form of performance, should equal to the vehicle's weight status in the systems/subsystems/components form. That obeys the second rule which was described in section 2.2. The example of weight statuses represented in the form of performance is shown in Figure 2.20, in which “HS” means high speed crash; “LS” means low speed crash; “AERO” represents aerodynamics; “PWT” represents powertrain; “AUT” represents autonomy; “TOT” means total. These acronyms are applicable for all of the sections and chapters in this thesis.

2.4.3 Radar graph and whole weight efficiency

Once the numerical representations of the performances and the weight statuses represented in performance form of the studied vehicle are ready, weights and performances could be combined together to consider the relative weight efficiency for each performance to plot the radar graph. For each performance, the relative weight efficiency of a studied vehicle is the ratio between the coefficient, i.e. the numerical representation of the performance, and the weight contributes to the performance of the vehicle divided by the one of the reference vehicle. Figure 2.21 shows the weight statuses, coefficients and the relative weight efficiencies of Renault ZOE ZE Intens 2013 and Nissan Leaf SV 2017. In the example, the model Nissan Leaf SV 2017 is set as the reference vehicle.

	WEIGHT		Coefficients		Relative weight efficiency	
	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017	Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017
Front HS	191,3	190,8	0,25	0,21	1,16	1,00
Front LS	50,7	48,4	1,14	1,15	0,94	1,00
Rear HS	88,4	100,6	0,58	0,56	1,17	1,00
Rear LS	34,6	33,6	0,58	0,56	1,00	1,00
Side HS	106,8	109,1	0,74	0,80	0,95	1,00
HVAC	18,8	18,5	22,21	19,34	1,13	1,00
AERO	16,4	20,5	1,33	1,32	1,27	1,00
PWT	181,1	157,9	1,26	1,24	0,89	1,00
AUT	270,4	287,6	0,44	0,41	1,15	1,00
NVH	163,9	160,7	7,00	7,00	0,98	1,00
OTHER	343,0	398,7	6,32	6,61	1,11	1,00

Figure 2.21, Weight statuses, coefficients and relative weight efficiencies.

Since Nissan Leaf SV 2017 is the reference vehicle, its relative weight efficiencies for all of the performances are 1.

The radar graph is based on relative weight efficiencies. The radar graph of the two vehicles is shown in Figure 2.22.

A measurement of overall relative weight efficiency of a vehicle is given by the geometrical mean of all of the relative weight efficiencies of the chosen vehicle. After calculation, the overall relative efficiency of Renault ZOE is 1.06.

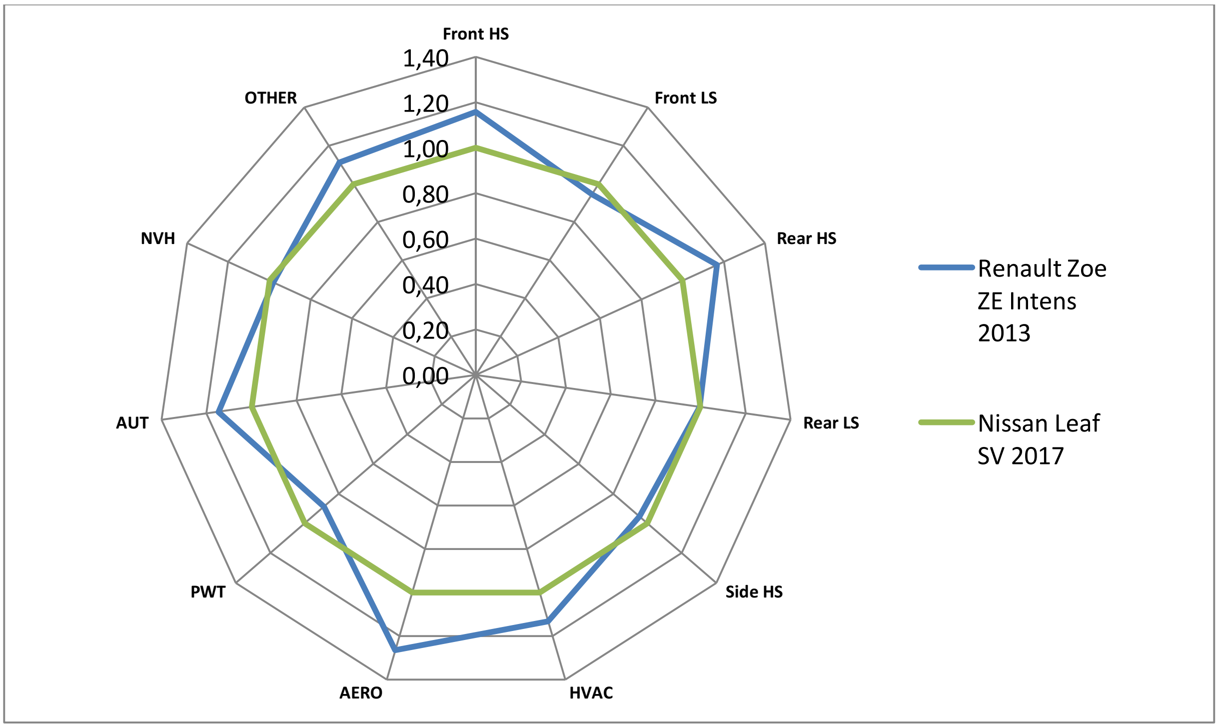


Figure 2.22, Radar graph of the studied vehicles.

2.5 Weight target setting

Thanks to the representation of weight status in performance form, there are two possible ways to set the weight target of a new vehicle. One solution is that keep the weight of the developing vehicle which contributes to each performance equal to the one of the reference vehicle meanwhile increase the performances as much as possible. The other way is that keep each determined performance of the developing vehicle as the one of the reference vehicle meanwhile control the weight to a level as lower as possible than the reference. An example of weight target setting is shown below by Figure 2.23, for the solution number 1, Figure 2.24, for the solution number 2, and Figure 2.25, the radar graph. Here also the model Nissan Leaf SV 2017 is utilized as the reference vehicle.

In practice, these two solutions are combined together for controlling weight and reaching a higher weight efficiency for each performance since it is not easy to modify a certain performance without changing any weight of the whole vehicle. Moreover, the cost of the developing vehicle should be taken into account since it will spend more to reach a higher performance, especially accompanied with weight reduction, of a system/subsystem/component.

	WEIGHT		Coefficients		Relative weight efficiency	
	Nissan Leaf SV 2017	New vehicle 1	Nissan Leaf SV 2017	New vehicle 1	Nissan Leaf SV 2017	New vehicle 1
Front HS	190,8	190,8	0,21	0,26	1,00	1,20
Front LS	48,4	48,4	1,15	1,27	1,00	1,10
Rear HS	100,6	100,6	0,56	0,56	1,00	1,00
Rear LS	33,6	33,6	0,56	0,56	1,00	1,00
Side HS	109,1	109,1	0,80	0,80	1,00	1,00
HVAC	18,5	18,5	19,34	18,37	1,00	0,95
AERO	20,5	20,5	1,32	1,45	1,00	1,10
PWT	157,9	157,9	1,24	1,24	1,00	1,00
AUT	287,6	287,6	0,41	0,61	1,00	1,50
NVH	160,7	160,7	7,00	6,50	1,00	0,93
OTHER	398,7	398,7	6,61	6,61	1,00	1,00

Figure 2.23, Example of weight target setting using solution 1.

	WEIGHT		Coefficients		Relative weight efficiency	
	Nissan Leaf SV 2017	New vehicle 2	Nissan Leaf SV 2017	New vehicle 2	Nissan Leaf SV 2017	New vehicle 2
Front HS	190,8	185,8	0,21	0,21	1,00	1,03
Front LS	48,4	43,4	1,15	1,15	1,00	1,12
Rear HS	100,6	95,6	0,56	0,56	1,00	1,05
Rear LS	33,6	28,6	0,56	0,56	1,00	1,17
Side HS	109,1	104,1	0,80	0,80	1,00	1,05
HVAC	18,5	18,5	19,34	19,34	1,00	1,00
AERO	20,5	19,0	1,32	1,32	1,00	1,08
PWT	157,9	142,9	1,24	1,24	1,00	1,10
AUT	287,6	252,6	0,41	0,41	1,00	1,14
NVH	160,7	165,7	7,00	7,00	1,00	0,97
OTHER	398,7	378,7	6,61	6,61	1,00	1,05

Figure 2.24, Example of weight target setting using solution 2.

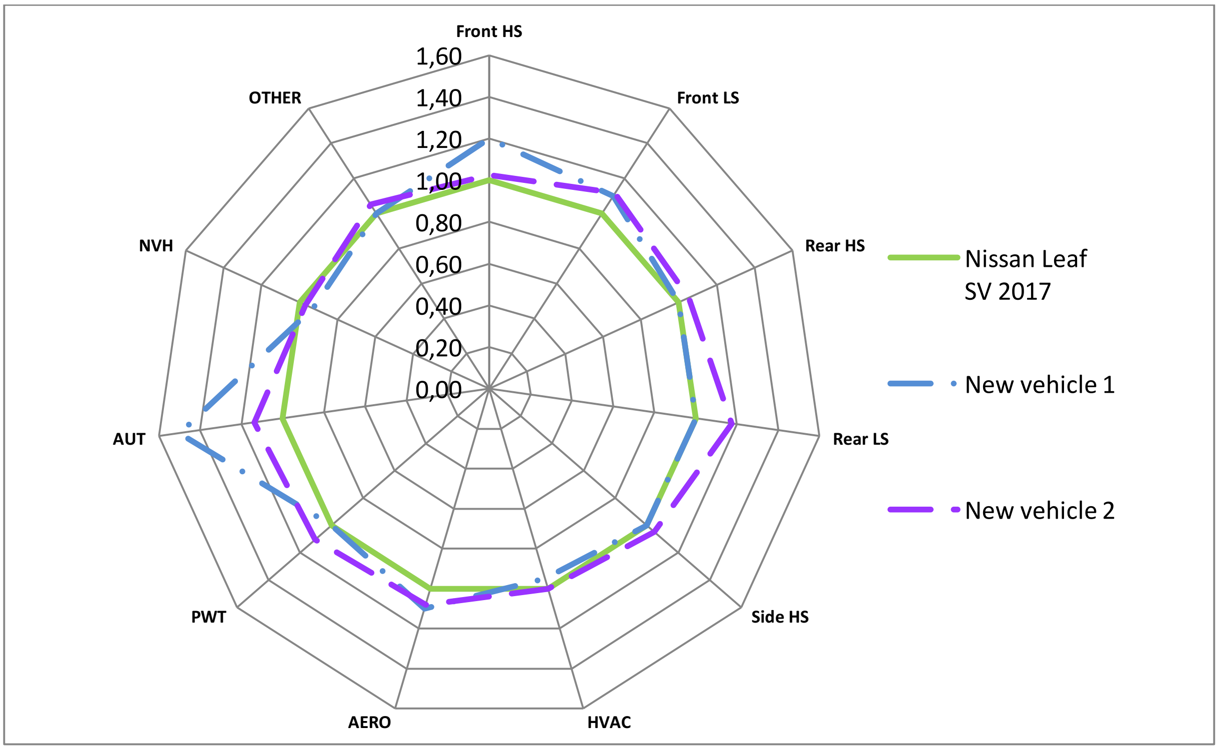


Figure 2.25, Radar graph of the studied vehicles.

CHAPTER 3

Battery and Autonomy Performance of BEV

3.1 Introduction to BEV

Electric vehicles first appeared in the middle of 19^{th} century. The first BEV was seen on the road shortly after the invention of rechargeable lead-acid batteries and electric motors in the late 1800s [4]. An electric vehicle held the vehicular land speed record until around 1900. Finally, due to the high cost, low top speed and especially short range, i.e. bad autonomy performance, of BEVs, compared to later ICE vehicles led to a worldwide decline in their use [5].

Thanks to the fast-developing technologies, the drawback of top speed was solved to an acceptable situation. Nowadays some models of BEV even have better performance in the field of top speed and acceleration than a conventional car in the same segment. As of March 2017, the model Tesla Model S P100D variant holds the record for the fastest acceleration of any production vehicle with a NHRA rolling start to 60 mph (97 km/h) in Motor Trend tests with 2.28 seconds (0 to 100 km/h in 2.36 seconds) in ludicrous mode [6]. And it was said by Tesla that the model Tesla Roadster model year 2020 will have an acceleration performance of 0-60 mph in 1.9 seconds, 0-70 mph (0-113 km/h) in 2.0 seconds and 0-100 mph (0-161 km/h) in 4.2 seconds. Moreover, it was claimed that the top speed of Roadster model year 2020 will be above 250 mph (400 km/h) [7].

The effect of the other two disadvantages of BEV performance becomes weaker and weaker. However, the cost and autonomy performance should be still carefully managed by automotive OEMs especially for autonomy performance to gain competitive positions of their products in the market.

On the contrary, BEV has several advantages compared to conventional ICE powered vehicle and they are the reasons why BEVs are promoted by governments around the world. One of the main advantages is the high energy conversion efficiency. For an electric motor of a BEV, the electric energy converted to mechanical energy for driving the vehicle could be up to 90% which is much higher than the fuel conversion efficiency for a conventional ICE powered vehicle. Another main advantage is the emission. A BEV has zero in-situ emission, since the energy for driving the vehicle comes from the electric energy stored in battery pack rather than from chemical combustion processes of fuels. For the emissions produced, a BEV has a clean level as the one of the method used to produce the electricity. A study shows that the amount of emissions from the least clean electricity grid is comparable to the best conventional vehicles while the emissions from the clean grid is much less than the amount produced by hybrid vehicles [8].

Battery pack is linked with the autonomy performance of a BEV directly. A battery pack with higher specific energy (the ratio between the energy capacity and the weight of the battery pack) and lower density is preferred for OEMs to equip on their products in autonomy point of view since certain autonomy performance could be guaranteed with a lower weight of the vehicle. However, the autonomy performance of a BEV is not only affected by the energy capacity and not only described directly by the maximum range when the vehicle is fully charged. In this chapter, the following will start from introducing battery pack briefly to giving a solution for evaluating autonomy performance for BEV.

3.2 Battery packs

3.2.1 Battery chemistry

The revolution of the chemistry of the battery for BEV has been continuing from the time when BEV first appeared. Nowadays, there are two major kinds of battery technologies utilized in electric vehicles are nickel metal hydride (NiMH) and lithium ion (Li-ion) [6].

For NiMH batteries, metal hydride (MH), which is a special type of intermetallic alloy capable of chemically absorbing and releasing hydrogen, is the active material in the negative electrode. The most widely used MH in NiMH currently is the AB_5 alloy with a $CaCu_5$ crystal structure, where A is a mixture of La, Ce, Pr and Nd, and B is composed of Ni, Co, Mn and Al. The active material in the positive electrode is $Ni(OH)_2$. The separator is typically made from grafted polyethylene (PE)/polypropylene (PP) non-woven fabric. The commonly used electrolyte is 30 wt.% KOH aqueous solution with a pH value of about 14.3. In some special designs for particular applications, certain amount of NaOH and LiOH are also added onto the electrolyte [9].

During charging, water is split into protons (H^+) and hydroxide ions (OH^-) by the voltage supplied from the charging unit. The proton enters the negative electrode, neutralizes with the electron supplied by the charging unit through the current collector, and hops between adjacent storage sites by the quantum mechanics tunnelling. The voltage is equivalent to the applied hydrogen pressure in a gas phase reaction and will remain at a near-constant value before protons occupy all of the available sites. OH^- generated by charging will add to the OH^- already present in the KOH electrolyte. On the surface of the positive electrode, some OH^- will recombine with protons coming from the $Ni(OH)_2$ and form water molecules [9]. The complete reaction for charging is as follows:

$$M + Ni(OH)_2 \rightarrow MH + NiOOH$$

A schematic example of the process described above is shown in Figure 3.1.

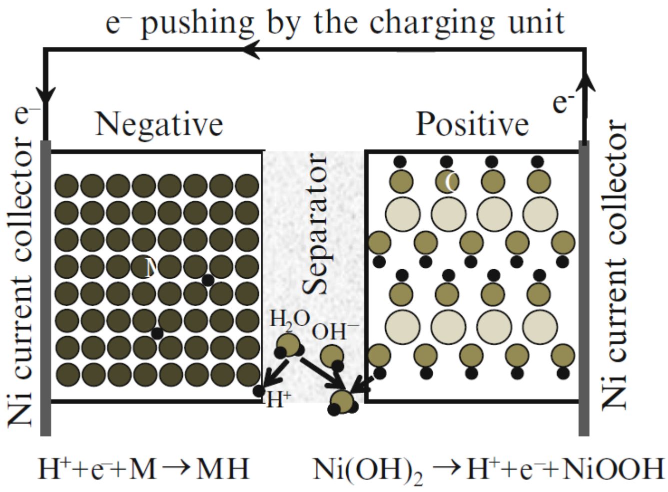


Figure 3.1, Schematic example of the charging operation of a NiMH battery [9].

The whole process is reversed during discharging.

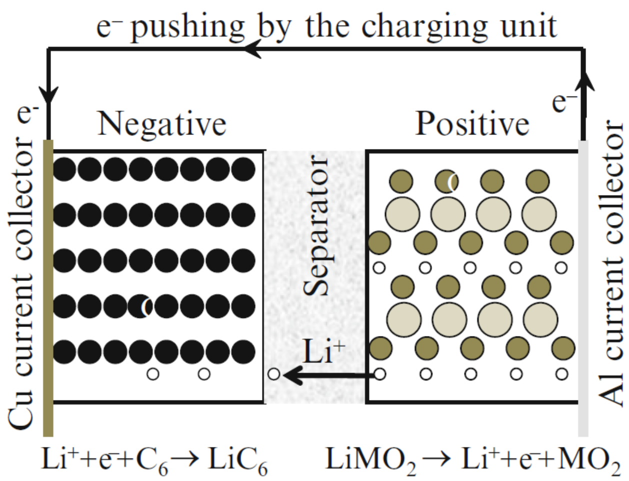


Figure 3.2, Schematic example of the charging operation of a Li-ion battery [9].

For Li-ion batteries, a similar schematic example is shown in Figure 3.2. The complete chemical reaction of the cell during charging, if graphite is used as the active material in the negative electrode, is:

$$C_6 + LiMO_2 \rightarrow LiC_6 + MO_2$$

The active material in the positive electrode is a Li-containing metal oxide, which is similar to $Ni(OH)_2$ in the NiMH battery but replaces the hydrogen with lithium [9]. During charging, Li ions, driven by the potential difference supplied by the charging unit, intercalate into the interlayer region of graphite [9]. The arrangement of Li^+ in graphite is coordinated by the surface-electrolyte-interface (SEI) layer, which is formed during the initial activation process [9]. The Li^+ hops onto the surface, moves through the electrolyte, and finally arrives at the negative electrode [9]. The oxidation state of the host metal will increase and return electrons to the outside circuitry [9]. During discharging, the process is reversed. Li ions now move from the intercalation sites in the negative electrode to the electrolyte and then to the original site in the $LiMO_2$ crystal, where "M" is Co, Ni or Mn. The commonly used electrolyte is a mixture of organic carbonates such as ethylene carbonate, dimethyl carbonate, and diethyl carbonate containing lithium hexafluorophosphate ($LiPF_6$) [9]. The separator is a multilayer structure from PP, which provides oxidation resistance, and PE, which provides a high-speed shutdown in the case of a short [9].

3.2.2 Electrode materials for Li-ion batteries

Currently all hybrid electric vehicles (HEVs) available in the market today use NiMH batteries because of its mature technology [9]. However, Li-ion batteries have become the standard power source for a wide range of electric/electrical devices including BEV due to their high energy density, which is 5 times greater than the one of lead-acid and twice the one of NiMH batteries [10]. Moreover, the advantages of low self-discharge rate, long cycle life and wide operating temperature range [11] suit the needs of BEVs and make Li-ion batteries have a dominant position in the applications to BEVs. In this section, the materials of different Li-ion batteries will be introduced.

For Li-ion batteries, the materials for electrodes especially for cathode, decide the performances of the battery deeply. A brief description of different types of active cathode material used for BEV battery is shown in Table 3.1.

Among the cathode materials, $LiCoO_2$ is the most popular one used in consumer product [9]. It has good capacity and cycle life but expensive and unsafe [9]. $LiMn_2O_4$ is commonly used in cell phones and in automobile (for example the battery pack of Nissan Leaf). It has the advantages of low cost and rate capability but also has the disadvantages of poor cycle and calendar life and relatively low specific capacity [9]. $LiFePO_4$ has the highest safety level and a low cost [9]. It also has the advantages of high power capability and long cycle life [9]. But it suffers from the problems of low calendar life and low capacity for both energy and voltage [9]. The advantages for both NMC (compound of Li, Ni, Mn, Co and O) and NCA (compound of Li, Ni, Co, Al and O) are the cost and capacity however NCA has safety concerns [9].

Material	Specific capacity, mAh/g	Voltage versus Li^+/Li, V
$LiCoO_2$	160	3.7
$LiMn_2O_4$	130	4.0
$LiFePO_4$	140	3.3
NMC	180	4.2
NCA	185	4.2

Table 3.1, Li-ion battery cathode materials and their properties [9].

The choices of the materials for anode is not so wide in the application point of view. Graphite is the most common material for anode, since it has a relatively high specific energy and a low cost. A graphite anode has an unstable SEI layer [12] especially at higher state of charges (SOCs) and a temperature higher than 40°, causes a severe performance degradation especially in the output power [9]. $Li_4Ti_5O_{12}$ (LTO) or similar Li-Ti oxides provide longer cycle life and calendar life than graphite but the specific capacity and higher voltage are drawbacks. Silicon for anode is still in research stage. It has low voltage and extremely large specific capacity however large volume expansion during charging needed to be solved [9].

3.2.3 Types of battery cell

A battery pack for BEV consists of tens to thousands individual cells [13], for supplying the operation current, voltage and energy needed by the vehicle. The cells inside a battery pack are organized into modules i.e. one module contains several cells. An example of battery pack assembly is shown in Figure 3.3.

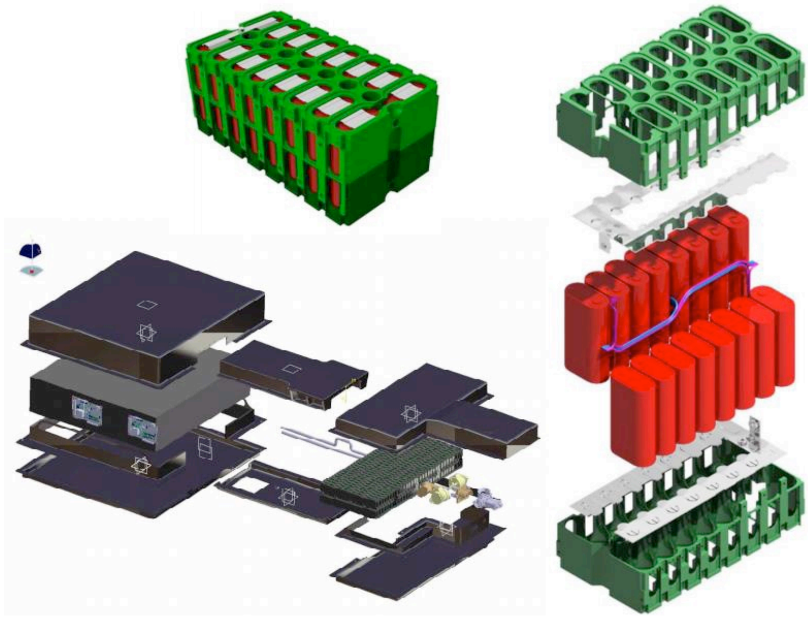


Figure 3.3, CAD representation of cells, modules and battery pack [13].

At present there are 3 kinds of cell utilized for BEV battery pack practically. Figure 3.4 shows a scheme of cylindrical cell, Figure 3.5 shows a scheme of prismatic cell and Figure 3.6 represents pouch cell.

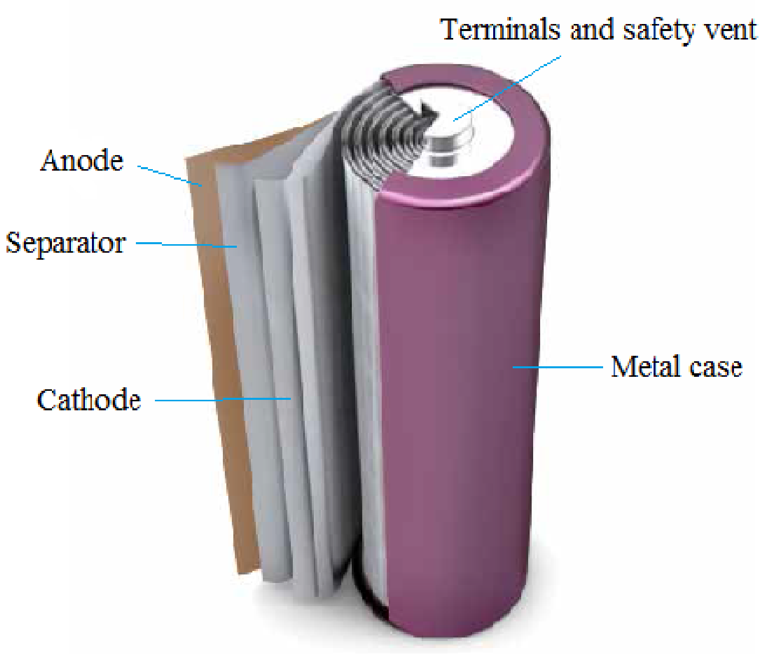


Figure 3.4, Scheme of cylindrical cell [14].

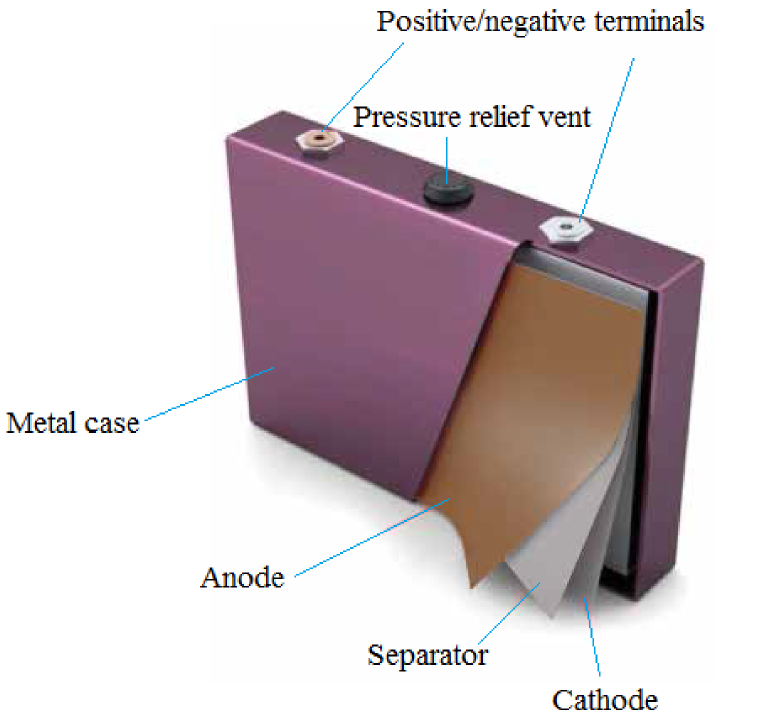


Figure 3.5, Scheme of prismatic cell [14].

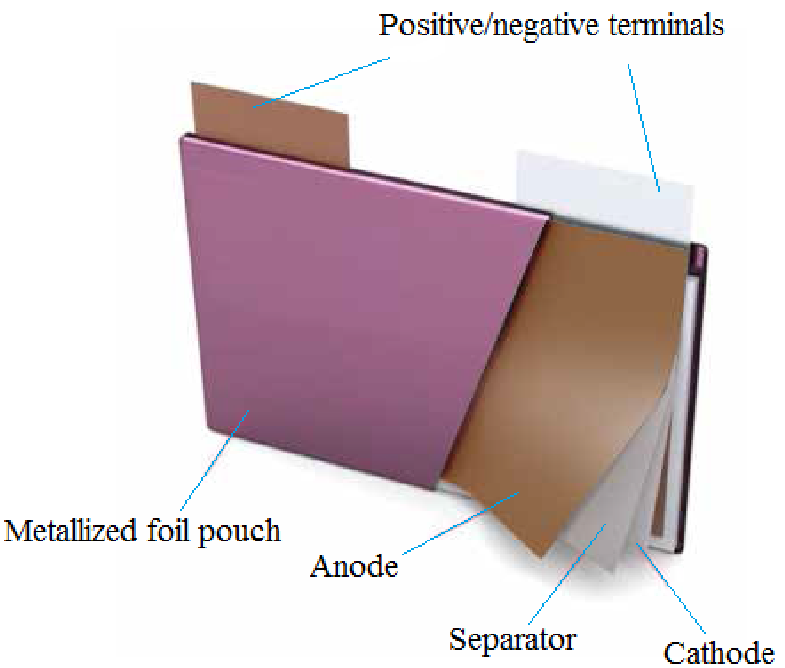


Figure 3.6, Scheme of pouch cell [14].

Cylindrical cells are widely utilized in consumer products such as laptop, power tools [13]. For automotive using, the interconnection and thermal management of cylindrical cells inside the battery pack should be highlighted. Pressure relief device should be integrated for safety reasons.

Prismatic cell has the advantages of structural stability, mechanical robustness and humidity protection [14]. Moreover, due to its shape, the packaging efficiency is higher than the one of cylindrical cell. And it also has the possibility to integrated with pressure relief vent.

The packaging material for pouch cells is minimized, therefore pouch cells have potentially higher energy density than prismatic cells for the same chemistry type [14]. Due to the shape of pouch cell, the packing efficiency for contributing a battery package is even higher than the one of prismatic cells and convenient for thermal management, however it requires more complex module design and restrains inside the battery pack [14].

3.2.4 Battery packs of some models

The information about battery packs of some BEVs at present are listed here in Table 3.2.

Model	Cell/module manufacturer	Cathode material	Cell type
Renault ZOE	LG Chem	NMC	Pouch
Nissan Leaf	AESC	$LiMn_2O_4$ based	Pouch
VW e-Up!	Panasonic	NMC	Prismatic
BMW i3	Samsung SDI	NMC	Prismatic

Table 3.2, Information about some battery packs [15-19].

The material NMC has several advantages and without obvious drawbacks which are described in the section 3.2.2 and that might be the reason why several OEMs and battery manufacturers adopted NMC as the cathode material for their lasted products.

3.3 A method for evaluating autonomy performance of BEV

The method which will be introduced in this section consists of the evaluation of two coefficients. The idea of the coefficients is started from how long of the distance can be covered by a BEV after a certain time of charging. The charging can be sorted into two general modes: long-time charging and short-time charging. The long-time charging is based on the maximum range for which the vehicle could cover. The short-time charging, which is based on the autonomy of the vehicle after charging for one hour, takes the combination of different charging modes into account. The two modes respectively consider the condition that the user stays in a place of residence meanwhile the vehicle is charging, and the condition that the user charges the vehicle outside from home or use the car for emergency conditions which does not have sufficient time for charging.

3.3.1 Long-time autonomy coefficient

The long-time autonomy coefficient represents how many NEDC cycles can be covered theoretically by the vehicle when the battery is fully charged. It is represented as:

$$C_l = \frac{a}{10.932}$$

where:

- a: autonomy (in km) of the fully charged BEV;
- 10.932: theoretical distance (in km) of NEDC cycle [20].

3.3.2 Short-time autonomy coefficient

The short-time autonomy coefficient is for the short-time charging. Similar with the theory for the short-time autonomy coefficient, it means that how many NEDC urban cycles can be covered theoretically by the BEV after 1 hour combined charging. The formula is:

$$C_s = \frac{\sum_i^n p_i \cdot a_i}{3.9761}$$

where:

- i: number of the considered charging mode;
- n: total number of available charging mode;
- p_i: portion of the charging time of the corresponding charging mode i according to the arithmetic progression;
- a_i: autonomy (in km) of 1 hour charging of the corresponding mode i;
- 3.9761: distance (in km) of the part UDC ECE-15 of NEDC (0-780 s interval, to simulate the urban driving condition) [20].

The purpose of applying arithmetic progression is to take a general accessibility of different charging modes into account. From customer point of view, a mode with a lower charging power means more economical and more convenient charging devices of the corresponding charging mode. And for a mode with a higher charging power, vice versa. Therefore, the lower the charging power, the higher the portion of the corresponding mode; the higher the charging power, the lower the portion of the corresponding mode.

It is worth to describe the portion p_i in details. Consider an arithmetic progression of which the sum is 1, according to its property:

$$\frac{(t_1 + t_n) \cdot n}{2} = 1$$

where i is the term number, t_i is the i-th term, n is the total number of terms.

Back to the application, if the portions of charging mode are considered as the terms of arithmetic progression:

$$\frac{(p_1 + p_n) \cdot n}{2} = 1$$

where p_1 is the portion of the mode with the lowest charging power, p_n is the portion of the mode with the highest charging power, n is the total number of charging mode but also the total number of terms of the progression. It should be noticed that, the equation cannot be solved since there is only one equation but there are two unknowns (p_1, p_n). One way to solve the problem is that inserting one "0" as a nominal last term of the progression and therefore the total number of terms becomes $n + 1$. Following this, the equation becomes:

$$\frac{(p_1 + 0) \cdot (n + 1)}{2} = 1$$

In this way the portion of the mode with the lowest charging power can be calculated as:

$$p_1 = \frac{2}{n + 1}$$

Since the last term is 0, the common difference is:

$$d = -\frac{p_1}{n}$$

Notice that the common difference is negative, means that a mode with a higher charging power has a lower portion. The reason was mentioned above.

After several steps of algebraic calculation, the general formula of portions of charging modes is:

$$p_i = \frac{2(n-i+1)}{(n+1)\cdot n}$$

Putting the general formula into the formula of the short-time autonomy coefficient described above, the explicit expression is:

$$C_s = \frac{\sum_i^n 2(n-i+1)\cdot a_i}{3.9761(n+1)\cdot n}$$

where:

- i: number of charging mode;
- n: total number of charging mode;
- a_i: autonomy (in km) of 1 hour charging of the corresponding mode i;
- 3.9761: distance (in km) of the part UDC ECE-15 of NEDC (0-780 s interval, to simulate the urban driving condition) [20].

3.3.3 Total autonomy coefficient and transformation law

For total autonomy coefficient:

$$C = \frac{C_l + C_s}{E_{B,t}/V}$$

where:

- $E_{B,t}$: total energy capacity of the battery pack, in kWh;
- V: volume of the battery pack, in m^3.

One thing should be noticed that both long-time and short-time autonomy coefficients C_l, C_s are no-unit numbers. The unit of the coefficient is m^3/kWh.

For the transformation law, it is necessary to divide the total coefficient by the weight of battery, for which the unit becomes $m^3/(kWh\cdot kg)$. The new value can be analysed that, to make it easy to be understood, with the same range performances:

- the lower the energy capacity of the battery;
- the lower the weight of the battery;
- the higher the volume of the battery;
- or, another way to explain, the lower the density of the battery,

the higher the efficiency of the battery. And also this transformation law follows the logic “higher is better” and obeys the forth rule which was introduced in the part 2.2.

3.4 Application of the method

The evaluation of the total coefficient mentioned in 3.3.3 needs the data about range and batteries. Table 3.3 and Table 3.4 contain the charging time of Renault ZOE ZE Intens 2013 and Nissan Leaf SV 2017 respectively with different available charging powers. The charging powers are numbered, with value increasing, starting from 1. Table 3.5 and Table 3.6 list the data of the two models needed for analysing autonomy performance.

In Table 3.6, since the accurate volumes of the battery packs of the studied vehicles are not available temporarily, volume parameter, of which the value depends on the shape of battery pack, is introduced for calculating the volume of battery packs with width, height and length. If the accurate volume is available, the volume parameter should be abandoned. The dimensions and the images of battery packs shown below come from A2mac1 AutoReverse environment.

Charging power	Charging time	Charging mode number
2.3 kW	10-11 h	1
3.7 kW	6.5 h	2
7.4 kW	3 h	3
11 kW	2 h	4
22 kW	1 h	5

Table 3.3, Charging time of Renault ZOE ZE Intens 2013 [21].

Charging power	Charging time	Charging mode number
2.3 kW	13 h	1
3.7 kW	8.1 h	2
7.4 kW	4 h	3
unknown	80% in 45 min	4

Table 3.4, Charging time of Nissan Leaf SV 2017 [22].

Model	Renault ZOE Intens 2013	Nissan Leaf SV 2017
Full autonomy	240 km	250 km
Autonomy after one hour charging with charging mode number 1	15 km	15 km
Autonomy after one hour charging with charging mode number 2	26 km	25 km
Autonomy after one hour charging with charging mode number 3	52 km	50 km
Autonomy after one hour charging with charging mode number 4	76 km	250 km
Autonomy after one hour charging with charging mode number 5	155 km	N/A

Table 3.5, Autonomy data of the analysed models [21, 22].

Model	Renault ZOE Intens 2013	Nissan Leaf SV 2017
Energy storage	22 kWh	30 kWh
Width	1228 mm	1126 mm
Height	330 mm	335 mm
Length	1620 mm	1540 mm
Volume parameter	0.45	0.6
Rough estimated volume	295.42 L	348.54 L
Weight	278.474 kg	295.706 kg

Table 3.6, Battery pack data of the analysed models.

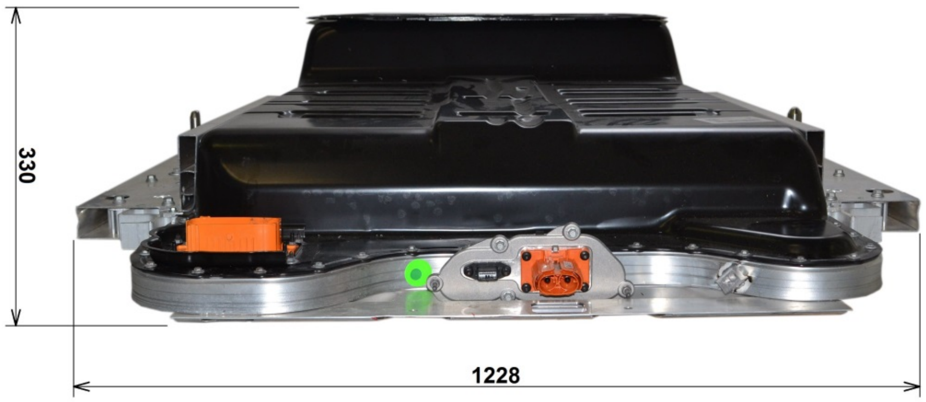


Figure 3.7, Front view of the battery pack of Renault ZOE ZE Intens 2013.

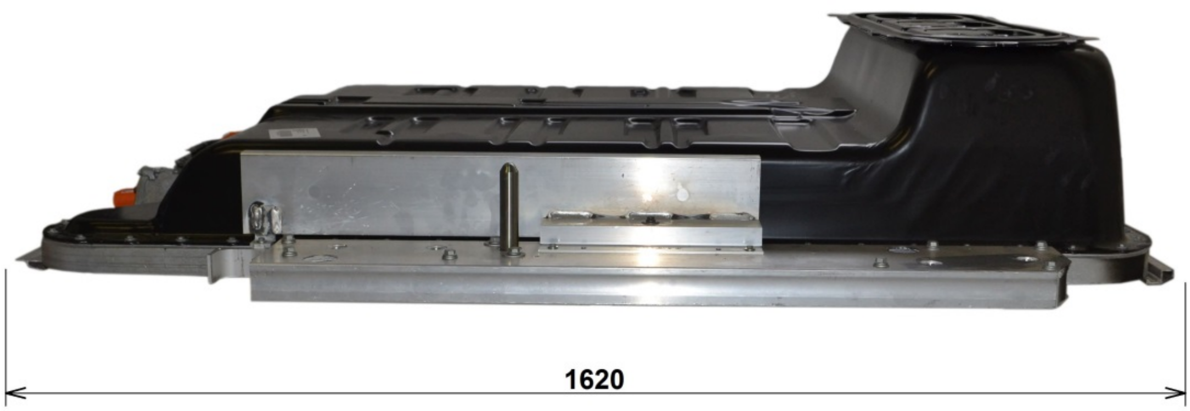


Figure 3.8, Side view of the battery pack of Renault ZOE ZE Intens 2013.

Figure 3.9, Profile view of the battery pack of Renault ZOE ZE Intens 2013.

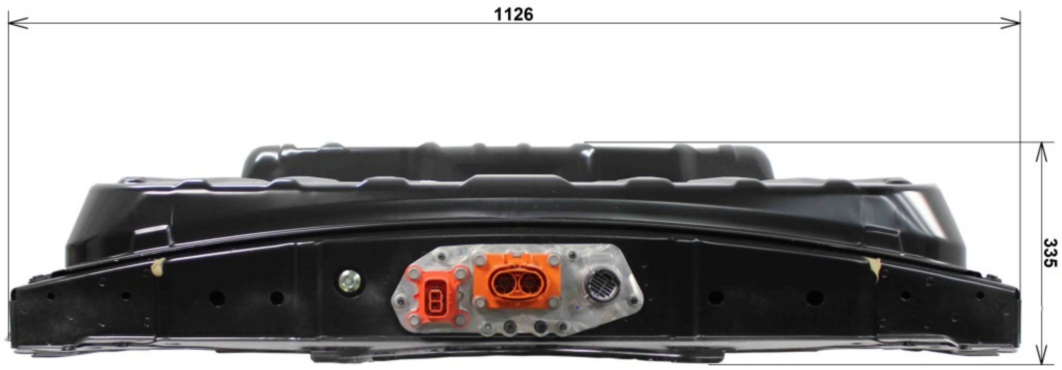


Figure 3.10, Front view of the battery pack of Nissan Leaf SV 2017.

Figure 3.11, Front view of the battery pack of Nissan Leaf SV 2017.

Figure 3.12, Profile view of the battery pack of Nissan Leaf SV 2017.

Table 3.7 shows the coefficients about autonomy of the two studied model after calculation.

For weight status in performance form, only battery pack has contribution to autonomy performance. Moreover, the weight of battery pack should not be totally counted for autonomy performance but should be split in a way also for the contribution to powertrain performance since the voltage and the current supplied by battery pack affect directly the output torque and angular speed of the electric motor and the battery management system is integrated in the battery pack. A suitable way for splitting is shown in Figure 3.13.

Model	Shor-time autonomy coefficient	Long-time autonomy coefficient	Total coefficient
Renault ZOE ZE Intens 2013	10.76	21.95	0.439
Nissan Leaf SV 2017	12.20	22.87	0.407

Table 3.7, Coefficients after calculations.

SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT	SAFETY					HVAC	AERO	PWT	AUT	NVH	OTHERS	TOT
				Front HS	Front LS	Rear HS	Rear LS	Side HS							
	4PIM	Battery									0,03	1,00		0,00	1,03

Figure 3.13, Contributions of battery pack.

SYSTEM	SUB-SYS	SUBSYSTEM DESCRIPTION	TH F A PWT		Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017		Renault Zoe ZE Intens 2013	Nissan Leaf SV 2017
					PWT			AUT	
	4PIM	Battery			8,1	8,6		270,4	287,6

Figure 3.14, Split weights of battery pack contribute to powertrain and autonomy performances.

Finally, as shown in Figure 2.10, section 2.4.3, the weight efficiency about autonomy performance of Renault ZOE Intens 2013 relative to Nissan Leaf SV 2017 is 1.15.

CHAPTER 4

Conclusions

4.1 Conclusion about the approach

In general, the approach which links weight and performances used in chapter 2 is powerful enough for benchmarking in the weight and performance point of view, even though the performance coefficient calculation method is an old and draft version. If the calculation method of coefficients, except the one for autonomy performance which is described in chapter 3, is improved into a more precise way, the result of benchmarking will be more realistic therefore it will have a higher possibility for cost and weight reduction and performance improvement.

This kind of approach can also be utilized for other performances of passenger vehicle which were not taken into account in chapter 2 and chapter 3 before. For example, handling performance and drivability could be added for analysis, like autonomy performance which is an additional performance for suiting the development of BEV described in chapter 3, to study the vehicles which are aimed at the field of handling.

Furthermore, not only passenger vehicles but also commercial vehicles even industrial vehicles have the possibility to use this kind of approach for weight management since the differences between passenger cars and other kinds of vehicles, as we say the relationship between weight and performance, are only the studied performances or evaluation methods of performances in the developing phase due to the different functions of different kinds of vehicle.

4.2 Conclusion about the method for evaluating autonomy performance of BEV

The method which was described in chapter 3 is precise enough to describe the autonomy performance especially the efficiency, which involves weight, density and volumetric energy density, of the battery pack of a BEV in a comprehensive way that the method considers not only the explicit need, which is the maximum range of the vehicle, of customers but also takes the applicable charging processes of the vehicle as an implicit demand of customers during the actual use into account. Moreover, all of the data needed for evaluation are easily to be gathered in reliable ways, for example the maximum range and the range after charging for one hour respected to different charging modes, even though the data are numerous.

During some test applications to the development of new product, this method provides powerful and realistic results for various segments of BEV. After the considerations of several professionals and managers, this method will be adopted as an internal standard by FCA.

References

1. SAE Motor Vehicle Dimensions J1100. (2009). 2nd ed.
2. Euroncap.com. (2012). Official Nissan Leaf 2012 safety rating results. [online] Available at: https://www.euroncap.com/en/results/nissan/leaf/10939.
3. Euroncap.com. (2015). Official Hyundai i20 2015 safety rating. [online] Available at: https://www.euroncap.com/en/results/hyundai/i20/20641.
4. Corrigan, D., and A. Masias. "Batteries for electric and hybrid vehicles, Reddy TB (ed) Linden's handbook of batteries." (2011).
5. Wikipedia contributors. "History of the electric vehicle." *Wikipedia, The Free Encyclopedia*. Wikipedia, The Free Encyclopedia, 9 Nov. 2017. Web. 16 Nov. 2017.
6. Markus, Frank (2017-02-07). "2017 Tesla Model S P100D First Test: A New Record — 0-60 MPH in 2.28 Seconds!". Motor Trend. Retrieved 2016-02-23.
7. "Elon Musk Unveils Tesla Semi, Roadster in 'Smackdown to Gasoline Cars'". *Nerdist*. 2017-11-17. Archived from the original on 2017-11-19. Retrieved 2017-11-18.
8. Anair, Don, and Amine Mahmassani. "State of charge, Electric Vehicles' Global Warming Emissions and Fuel-Cost Savings across the United States," Union of Concerned Scientists." (2012).
9. Young, Kwo, et al. "Electric vehicle battery technologies." *Electric Vehicle Integration into Modern Power Networks*. Springer New York, 2013. 15-56.
10. Xue, Nansi. "Design and Optimization of Lithium-Ion Batteries for Electric-Vehicle Applications." (2014).
11. Linden, David, and Thomas B. Reddy. "Handbook of Batteries. 3rd." (2002).
12. Moss, Pedro L., et al. "Investigation of solid electrolyte interfacial layer development during continuous cycling using ac impedance spectra and micro-structural analysis." *Journal of Power Sources* 189.1 (2009): 66-71.
13. Miller, Peter. "Automotive Lithium-Ion Batteries." *Johnson Matthey Technology Review* 59.1 (2015): 4-13.
14. "Johnson Matthey Battery Systems: Our Guide to Batteries", 2nd Edn., Johnson Matthey Plc, Dundee, UK, 2012.
15. "LG Chem." *Lgchem.Com*, 2017, http://www.lgchem.com/global/vehicle-battery/car-batteries/product-detail-PDEB0001.
16. Lima, Pedro. "Volkswagen's Strategy For Batteries - Push Evs." *Push Evs*, 2017, http://pushevs.com/2016/09/13/volkswagens-strategy-for-batteries/.
17. Lima, Pedro. "What Makes A Good Electric Car Battery? - Push Evs." *Push Evs*, 2017, http://pushevs.com/2015/09/22/what-makes-a-good-electric-car-battery/.

18. "Cell, Module, And Pack For EV Applications | Automotive Energy Supply Corporation." *Eco-Aesc-Lb.Com*, 2017, http://www.eco-aesc-lb.com/en/product/liion_ev/.
19. "Automotive Battery - Battery Pack | Samsung SDI." *Samsungsdi.Com*, 2017, http://www.samsungsdi.com/automotive-battery/products/battery-pack.html.
20. Wikipedia contributors. "New European Driving Cycle." *Wikipedia, The Free Encyclopedia*. Wikipedia, The Free Encyclopedia, 9 Nov. 2017. Web. 24 Nov. 2017.
21. "Ricarica Renault Zoe R90 (22 Kwh) - E-Station." *E-Station*, 2017, http://www.e-station.it/scheda-auto-elettrica/renault-zoe-r90-22-kwh.
22. "Ricarica Nissan Leaf 30 Kwh - E-Station." *E-Station*, 2017, http://www.e-station.it/scheda-auto-elettrica/nissan-leaf-30-kwh.