

TYRE DESIGN PROCESS

Modelling of Technical Design Process

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Summary: *This document comprises an effort to develop a design process strategy for a new series of the already knew Michelin's tyre "Primacy 3ST" in order to improve its characteristics and satisfy customers' new requirements and trends.*

Key words: Tyre, Michelin, Primacy 3ST, Product Requirements, Design

2. INTRODUCTION

Within this report, the technical design process for a new series of "*Primacy 3ST*" tyre will be developed. The next chapter will provide an overview of the case study upon which the project is based with a market and competitors analysis where the product and company are situated in.

In Chapter 3, after chapter's 2 decisions, the product requirements are defined and implemented in a Quality Function Deployment to obtain insight into which components are most crucial to the product requirements.

Still highly focused on product level, Section 4.3 uses the principle of DPU-modelling to interconnect performance analysis methods for assessing this product quality. This provides the required input to specify in which sequence the design information flows throughout the design process and forms the basis for the design strategy of the product in Section 4.3.1.

Chapter 4 goes from the different design phases until the company's organization which are related with the DPU modelling.

It is of significant importance that the project is carried out in such way it complies with the initial plan and that we also learned from it. Therefore chapter 5 deals with the monitoring and controlling the performance of the project and the product under design.

Apart from designing the structure of the design process, addressing the way information is flowing between the project stages, involved disciplines and design team members is a crucial part of modelling the design process. Only by means of proper documentation and communication it is made sure the design is running smoothly and decisions are traceable and controllable. This aspect of process design is addressed in chapter 6 and in section 4.4.

3. COMPANY BACKGROUND

Michelin is a French tyre manufacturer based in Clermont-Ferrand in the Auvergne region of France. It is one of the five largest tyre manufacturers in the world along with Goodyear, Continental, Pirelli and Bridgestone. Michelin supplies tyres for all types of vehicles – cars, vans, trucks, buses, farm machinery, earthmovers, mining and handling equipment, tramways, metros, aircraft, motorcycles, scooters and bicycles. This ability to deliver effective solutions in response to widely varying expectations and usage patterns, depending on the country or region, has positioned the Group at the forefront of every one of these segments.

Michelin, is dedicated to enhancing its clients' mobility, sustainably, designing and distributing the most suitable tyres, services and solutions for its clients' needs. Providing digital services, maps and guides to help enrich trips and travels and make them unique experiences. Besides, it is also worried about developing high-technology materials that serve the mobility industry. In order to do that, the company defined a mission for 2020: *"Michelin aims to strengthen its leadership in sustainable mobility and become one of the world's top-performing companies in fulfilling all of its commitments to responsibility."*. Their work in this field can be seen on appendices A.

The company is present in 170 countries, has 111,700 employees and operates 68 production facilities in 17 countries which together produced 187 million tyres in 2016.

Michelin's vision: *"Because we believe that mobility is essential for human development, we are innovating passionately to make it safer, more efficient and more environmentally friendly. Our priority and firm commitment is to offer our customers uncompromising quality. Because we believe that all of us deserve personal fulfillment, we want to enable everyone to do his or her best, and to make our differences a valuable asset. Proud of our values of respect for customers, people, shareholders, the environment and facts, we are all sharing the adventure of better mobility for everyone."*

2.1 Target market and competitors analysis

In appendices B – Economic analysis, is shown that in 2016, Michelin was the second placed in world market division, right behind Bridgestone which is a good hint to continue the company's ways of working. The company's biggest market in the previous years was "Passenger car and Light Truck & Related Distribution" which is also shown in appendices B. Based on this information, it's important to ensure the continuity of this market confidence on the company and develop a tyre that is suitable for the whole new automotive industry and their needs.

With Michelin's mission for 2020 in mind and following the economic analysis, the objective is to make sure that the company has a model that is suitable to most citizens cars needs and that is also cheap and "green".

Characteristics	Target
Demographics	Every person with a passenger car or light truck
Usage	Road and light off-road conditions
Benefits	Green tyres with reliable performance and low cost
Geographic location	Places with all weather conditions except heavy snow

Figure 1 – Target market characteristics

Since the company already has a tyre for this market, "*Primacy 3ST*", a performance evaluation will be made to know if it is suitable for the customers' new necessities.

2.1.1 Performance analysis

Identifying consumers' needs is always the first stage of the life of a tyre. Answering to their expectations means delivering the required product on time and respecting quality.

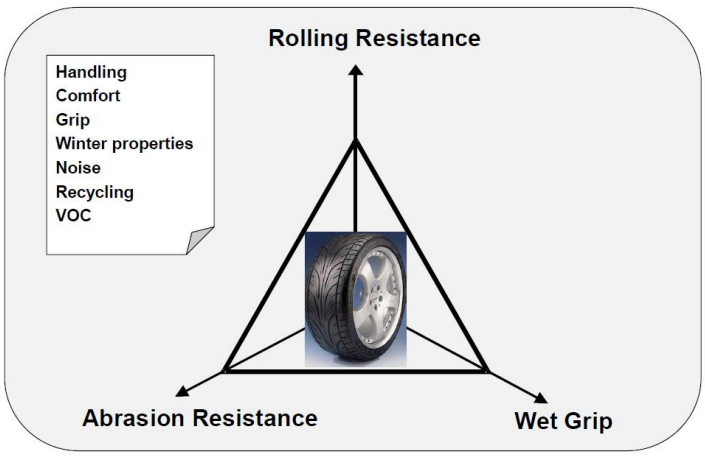


Figure 2 – Tyre requirements: Magic triangle, [4]

As shown on figure 2, rolling resistance, abrasion resistance and wet grip are the most important requirements for a tyre in terms of engineering. These are the basics requirements for every tyre since rolling resistance is directly related to fuel efficiency and abrasion resistance is related to new material, manufacturing processes and wastes of the previous tyres. These two properties are very important for sustainability which is an important topic in the new automotive industry and in the Michelin mission for the future. Besides, the wet grip is related with the safety of the car. Nevertheless, exist more parameters that are also important and will take a significant role on the legal standards and in one of the strategies that Michelin uses to improve their products: Voice of the customer.

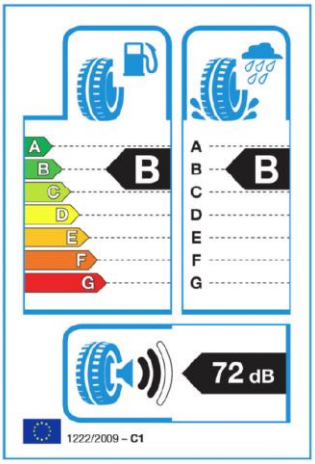


Figure 3 – Example of European legal tyre standard label at November 2012, [4]

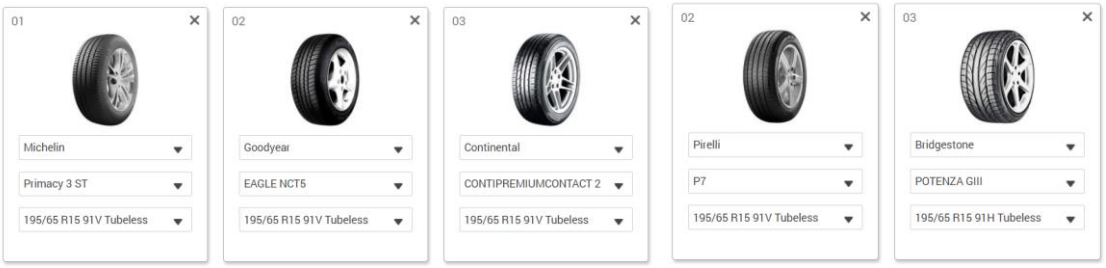
The requirements in this label are:

- Fuel efficiency ∝ Rolling resistance (one of the three most important requirements);
- Wet grip (one of the three most important requirements);
- Noise (none of the three most important requirements).

When the *"Primacy 3ST"* was launched (2013), it was one of the best tyres on the market. Michelin have done tests to its performance and after analyzing the results they conclude that:

- LEQ (Equivalent Sound Pressure Level) – 8% quieter than average of competitors;
- Wet grip – 2.2 meters shorter braking distance on wet roads compared to leading competitors;
- Durability (abrasion resistance) – 25% better in longevity compared to previous generation;
- Fuel efficiency (rolling resistance) – Average fuel efficiency compared to leading competitors.

After 4 years, the customers' demands as well as the competitors' tyres characteristics may have changed, so it's necessary to compare them to know how well is *"Primacy 3ST"* performing. In this comparison, the tyre's characteristics are evaluated from the point of view of the customer, for example, fuel saving instead of rolling resistance.



Characteristics\Company	Michelin	Goodyear	Continental	Pirelli	Bridgestone
Price	>	<	<<	=	>>
Handling	4.5/5	3.9/5	4.2/5	4.5/5	4.5/5
Fuel saving	4.2/5	4/5	3.7/5	5/5	4.5/5
Safety	4.2/5	4/5	3.7/5	4.3/5	4.5/5
Ride comfort	4.1/5	4.6/5	3.6/5	4.9/5	4.5/5
Durability	3.1/5	3.7/5	3.1/5	4.1/5	4/5

Figure 4 - Tyre comparison between the same variant but different models

As shown on figure 4 and making a fast analysis with all the parameters, is possible to conclude that the *"Primacy 3ST"* was one of the best tyres when was launched, but now, compared with the new ones for the same target market, it isn't anymore. It is only better than the Continental model between the top 5 tyres manufacturing companies. To secure the market as shown before, it's necessary to improve this model after all this time.

4. TYRE'S REQUIREMENTS

3.1 Voice of the costumer

Customer-focused innovation has long been a Michelin growth driver and a powerful vector of differentiation. As mentioned before, Michelin usually uses the "Voice of the Customer" approach to evaluate their tyres performance in the customer's point of view. Michelin has two types of customers, the automotive industry and the regular citizen.

3.1.1 Companies

The voice of the customer is made using teams of specialists inside each of their customers' companies to identify needs, problems, good points and suggestions for new products.

Surveys were done by the teams in order to understand the customers' new requirements to be implemented in the new "*Primacy 3ST*". The feedback from the customers based on their drive experience were collected in terms of comparison, Figure 4. The specialists' teams after analyzing the results concluded that the problems to be improved are:

- The tyre price should decrease;
- Increase grip between the road and tyre to improve the low handling and safety of vehicle;
- Low generation of lateral force in turn due to cornering grip results in low handling;
- It's necessary to decrease the rolling resistance;
- Decrease the noise generated so the ride could be more comfortable;
- Increase the durability of the tyre because it has too much abrasion.

3.1.2 Regular citizen

Performing some analyzes in some "online forums" it was concluded that everyone looks for the automotive industry evaluation of the tyres plus the warranty and price.

3.2 Michelin's requirements

One of the most important objectives is to reduce the impact on the environment so in order to do that, it's necessary to reduce the tyre's rolling resistance, abrasion resistance and improve the manufacturing processes.

18% of the worldwide CO2 emission is due to mobility (3/4 from road traffic). European legislation is trying to reduce this lowering the maximum allowable value of CO2 weight per kilometer. Based on this, for passenger cars, with light commercial tyres, the European limit for rolling resistance is becoming tougher as shown in the table:

Year	Limit value [Kg/t]
2012	10.5
2020	9.0

Figure 5 – Maximum allowable value for rolling resistance in Europe, [4]

Other important measure is the reduction of abrasion which consequently will have a contribution for VOC (Volatile Organic Compound). Besides, the reduction of "material consume" impact in the world can be achieved through the reduction of abrasion and the use of recycling processes.

Improvements on manufacturing processes will also decrease:

- VOC and CO_2 emissions;
- Waste production and landfilled waste;
- Energy and water consumption.

The company's requirements that will be use are only the ones directly related with the tyre which is the product's design that is developed in this report. The manufacturing requirements won't be discussed further on.

3.3 Product requirements

The customers' and company's requirements, together with the legal standards (Figure 3 and 5), are the inputs for the technical design process. Now, it's possible to think about the technical aspects to fulfill the product requirements and the product components related with them. Further on, a *QFD – Quality Function Deployment* analysis will be implemented to evaluate the contribution of each technical aspect and component to the product requirements.

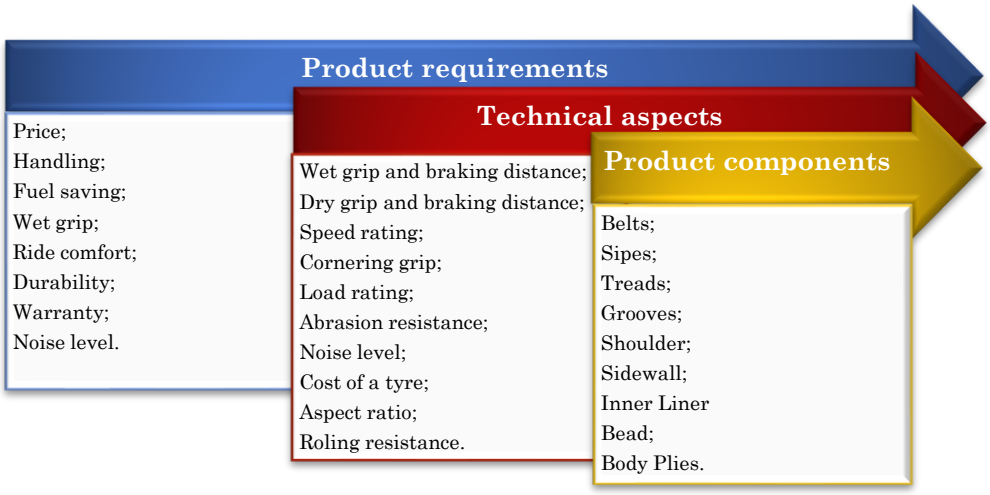


Figure 6 – Technical aspects and product components related with product requirements

3.4 Quality Function Deployment

Quality function deployment (QFD) tool is used to translate the voice of the customer (VOC) into product specifications. QFD offers a customer-oriented approach, supporting design teams in developing new products based on an assessment of customer needs. Customer needs are translated into design attributes, which are then deployed in process and quality requirements. In this case, as shown before, the product requirements are not only customers' needs. In this report, the QFD will be only composed by two stages.

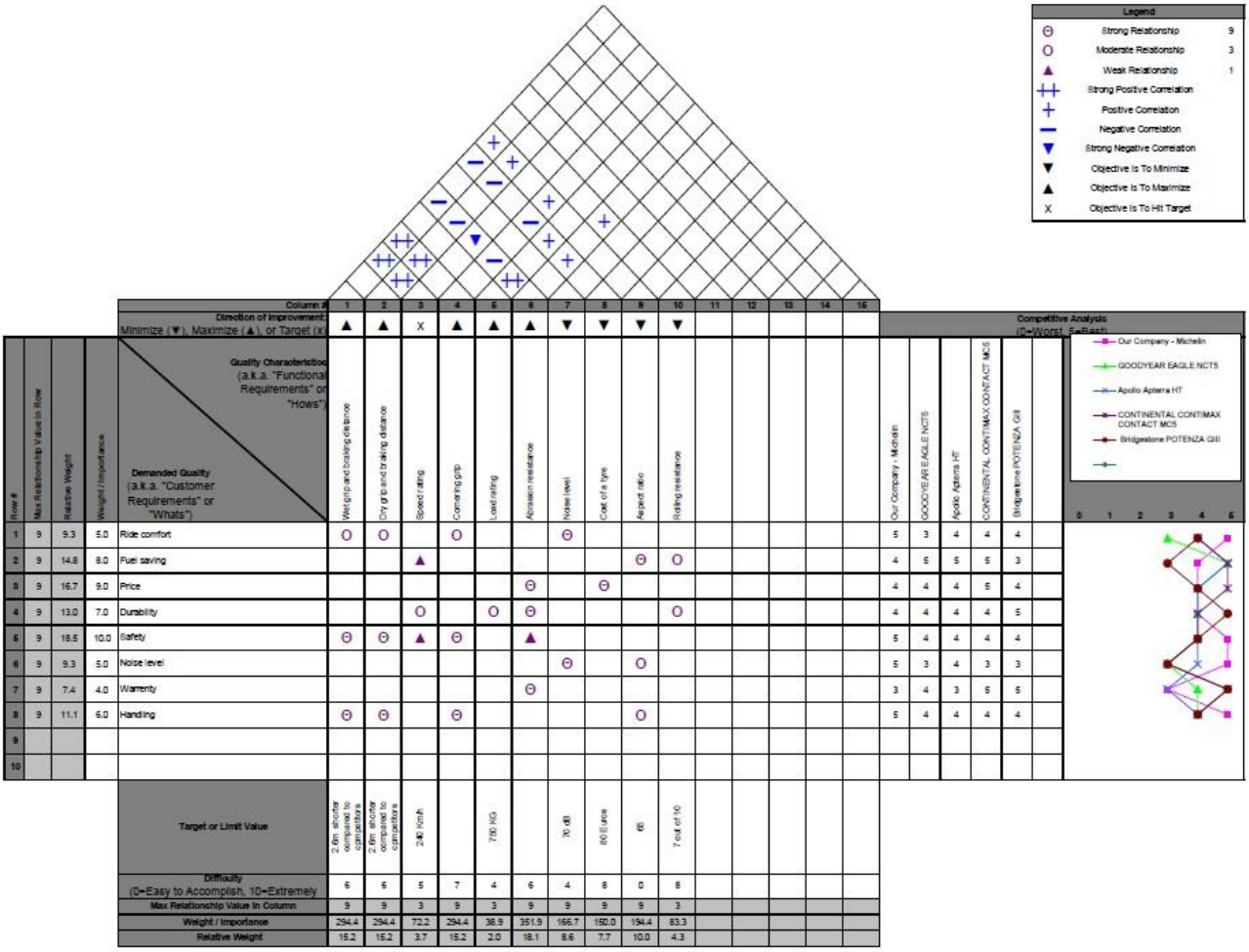


Figure 7 – House of Quality 1

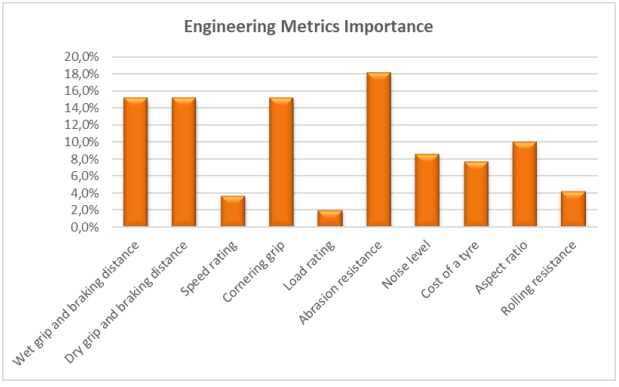


Figure 8 – Relative importance of engineering metrics from first phase of QFD-analysis

From figure 8, it's possible to conclude that abrasion resistance, wet grip, dry grip and cornering grip are the "Critical to Quality" parameters since they have more influence on the product requirements.

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Hows") / Demanded Quality (a.k.a. "Whats")	Belts	Sipes	Tread	Grooves	Shoulder	Sidewall	Inner liner	Bead	Body plies
1	9	15.2	294.4	Wet grip and braking distance	○	⊙	⊙	⊙	○				○
2	9	15.2	294.4	Dry grip and braking distance	○	⊙	⊙	▲	○				○
3	9	3.7	72.2	Speed rating		⊙	⊙	○	▲				⊙
4	9	15.2	294.4	Cornering grip	⊙	⊙	⊙	○	⊙				○
5	9	2.0	36.9	Load rating						⊙	○	○	⊙
6	9	18.1	351.9	Abrasion resistance	▲	○	⊙	▲	⊙				▲
7	9	8.6	166.7	Noise level	○				▲				⊙
8	9	7.7	150.0	Cost of a tyre	⊙	○	○	○	○	▲	○	⊙	⊙
9	9	10.0	194.4	Aspect ratio	▲				○	⊙	○		⊙
10	9	4.3	83.3	Rolling resistance	▲				○				⊙
11													
12													
13													
14													
15													
				Target or Limit Value									
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	7	5	7	5	6	4	4	6	8
				Max Relationship Value in Column	9	9	9	9	9	9	3	9	9
				Weight / Importance	356.3	520.7	629.5	249.7	469.2	115.9	59.3	75.6	481.9
				Relative Weight	12.0	17.6	21.3	8.4	15.9	3.9	2.0	2.6	16.3

Figure 9 – House of quality 2

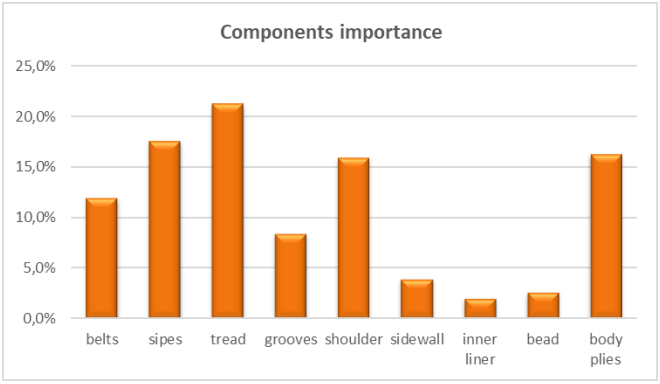


Figure 10 – Relative importance of tyre's components from second phase of QFD-analysis

From figure 10, it's possible to conclude that the tread, sipes, body plies and shoulder are the "Critical to Quality" components since they have more influence on the product requirements.

5. DESIGN PROCESS MODEL

4.1 Product description

Michelin has already set its standard in the global premium tyre market, with particularly strong position in high performance passenger car. Michelin's *"Primacy 3ST"* is the largest selling passenger car tyre up to date. The success of this tyre comes from the meeting of customer demands, performance of the tyre and strength of Michelin brand, supported by the dynamic innovation in products and services, which are highly appreciated by the customers. This success must be deployed continuously to beat back the competition.

Continuous innovations in the product development of *"Primacy 3ST"* is being implemented to have a better performance & quality. Technical innovations are made on distinct parts of the tyre which influences the performance of the tyre. Image below, shows the distinct components of the *"Primacy 3ST"*, which influence its performance.

A. Belts;
B. Sipes;
C. Tread;
D. Grooves;
E. Shoulder;
F. Sidewall;
G. Inner Liner;
H. Bead;
I. Body Plies.



Figure 11 – Primacy 3ST

4.2 Design phases of product development

Product development of Michelin's *"primacy 3ST"* tyre refers collectively to the entire process of identifying a market opportunity, creating a product that appeals the identified market, and finally, testing, modifying and refining the product until it is ready for full production. Developing a new product is hard, time consuming and costly. Great products are not simply designed, but instead they evolve over time through countless hours of research, analysis, design studies, engineering and prototyping efforts, and finally, testing, modifying, and re-testing until the design has been perfected. These activities take place in the different design phases of the product development. A methodical design phases in the product development is shown below:



Figure 12 – Design phases phase

Description of each design phase is explained in the next sections along with the different tools used in each phase and product development activities carried by Michelin in the different stages of development.

4.2.1 Problem analysis

During this phase of product development, Michelin Identify its stakeholders to understand their roles as they pertain to the "*Primacy 3ST*" product. A marketing strategy is developed to identify the competitors and evaluate their strategies to determine their strengths and weaknesses relative to those of "*Primacy 3ST*". With this evaluation of marketing strategy plan, Michelin establish what makes the development of the tyre with respect to passenger cars segment and therefore, Michelin plays with the different attributes in order to attract the target market. The goals of the product are identified based on the perspective of customer and business requirements. These goals are compared with the competitors' product in the same segment to analyze the performance of each tyre's attribute.

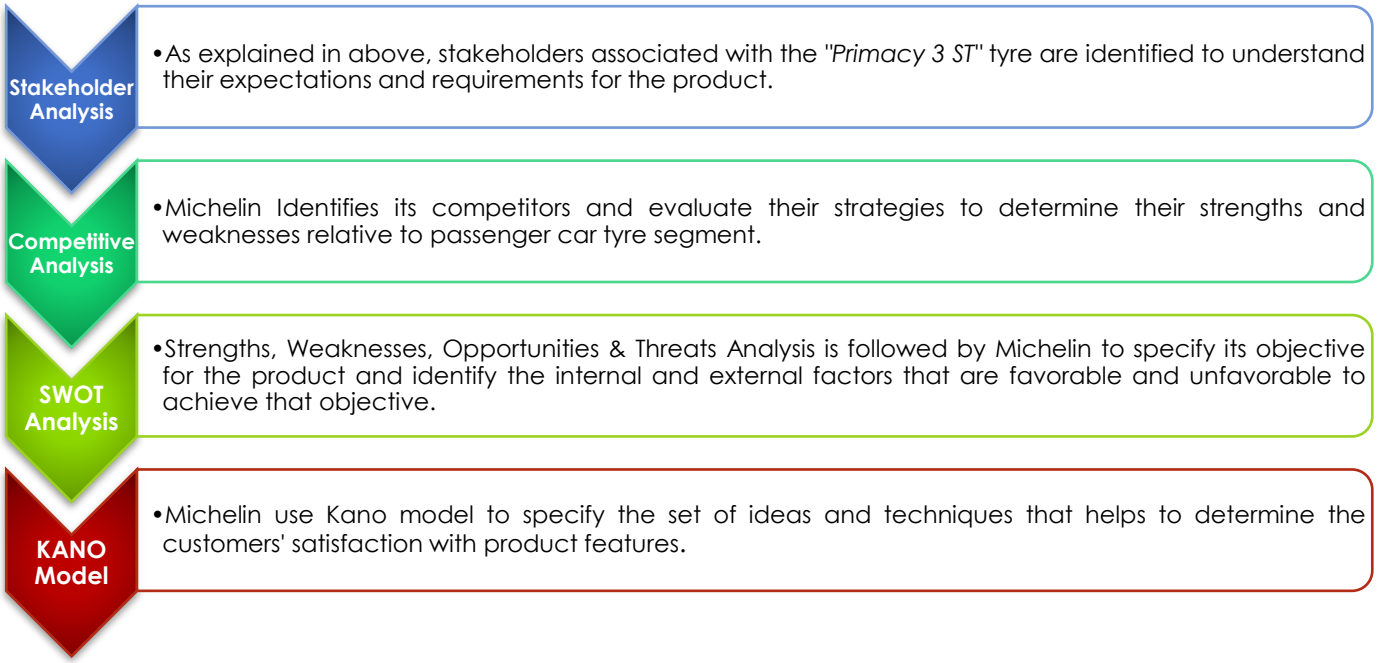


Figure 13 – Tools used in problem analysis phase

4.2.2 Conceptual design

Concept design is a very crucial stage of product development. During this stage, the needs of the customer are identified, competitive products are reviewed, product specifications are defined, a product concept is selected, an economic analysis is done, and the development of project is outlined.

Customer-focused innovation has long been a Michelin growth driver and a powerful vector of differentiation. The company promise, as expressed in "*Michelin Total Performance*", is to constantly innovate and deploy advanced technologies to deliver more performance in "*Primacy 3ST*" product. This can be achieved when certain design tools are deployed in the conceptual phase of product development.

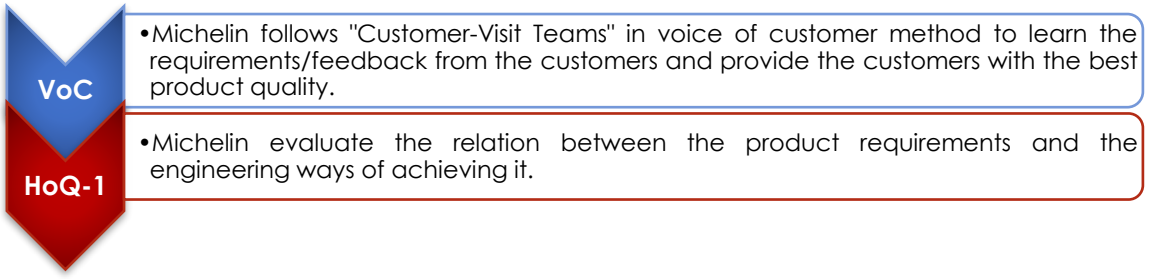


Figure 14 – Tools used in conceptual design phase

4.2.3 Layout design

In this phase of product development, the task of designing the architecture of the product is carried out. In previous phases of product development, the team was focused on the core product idea, and the prospective design was largely based on overviews of a tyre rather than in-depth design and engineering. Once the development plan for Michelin "*Primacy 3ST*" is approved, marketing may begin to develop ideas for additional product options and add-ons. Designers and engineers develop the product architecture in detail, and manufacturing determines which components of a tyre should be made in house and which should be purchased, and identifies the necessary suppliers.

Michelin's product architecture defines the primary functional systems and subsystems of a tyre and how these systems are arranged to work as a unit defining their layout. System level design impacts a number of important attributes in the development of a tyre such as standardization of components, modularity, options for change later on, difficulty of manufacturing and how the project is divided into manageable tasks and expenses. If a family of tyres or upgrades and add-ons are planned by Michelin, the architecture of the product would determine the commonality of components and the ease with which upgrades, and add-ons can be installed. A system or subsystem borrowed from another product within the company's line will economize on development, tooling and manufacturing costs.

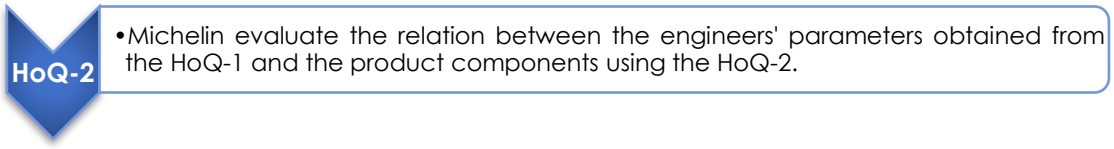


Figure 15 – Tool used in conceptual design phase

4.2.4 Detail design

In this phase of product development, the necessary engineering is done for every component of the product. During this phase, each part of the tyre is identified and developed. Geometry, tolerances, materials, simulations and finishes of the tyre are defined and the design is documented with drawings, computer files or reports. Manufacturers and developers are using 3D solid modelling programs such as Pro-Engineer, CATIA, Solidworks, AutoCAD & Unigraphics. 3D computer models form the core of today's rapid prototyping and rapid manufacturing technologies.

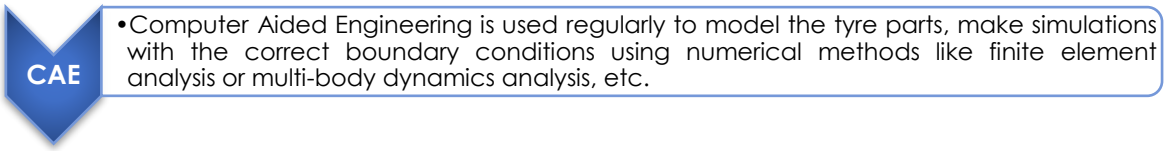


Figure 16 – Tool used in detail design phase

4.2.5 Test and refinement

During the testing and refinement phase of product development, Michelin tests and builds prototypes of "*Primacy 3ST*" tyre. Michelin use these prototypes to determine whether the performance of the tyre matches the specifications, and to uncover design shortfalls and gain experience in the field with the tyre in use. Having reliable test data from multiple prototypes is the best way to lay a solid foundation for the engineering development in this phase. Michelin takes care to eliminate variables and have a reliable test process because the quality of the test data will be important for further "*Primacy 3ST*" refinement and to improve Michelin's knowledge.

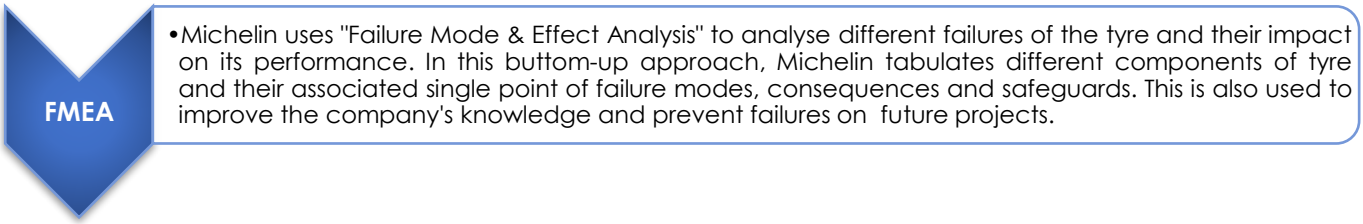


Figure 17 – Tool used in test and refinement phase

4.2.6 Production ramp-up

The production ramp-up phase is of great importance for Michelin in the product development and has a significant impact on the *"Primacy 3ST's"* success in terms of costs and time to reach full capacity utilization (time-to-volume). During the production ramp-up the instability of the production system and the quality of manufactured products are significantly influenced by the manufacturing technologies deployed. The manufacturing team is trained as the first products are being constructed. The comparatively slow product build provides time to work out any remaining problems with supplier components, fabrication, and assembly procedures. The staff and supervisory team are organized, beginning with a core team, and line workers are trained by assembling production units in Michelin.

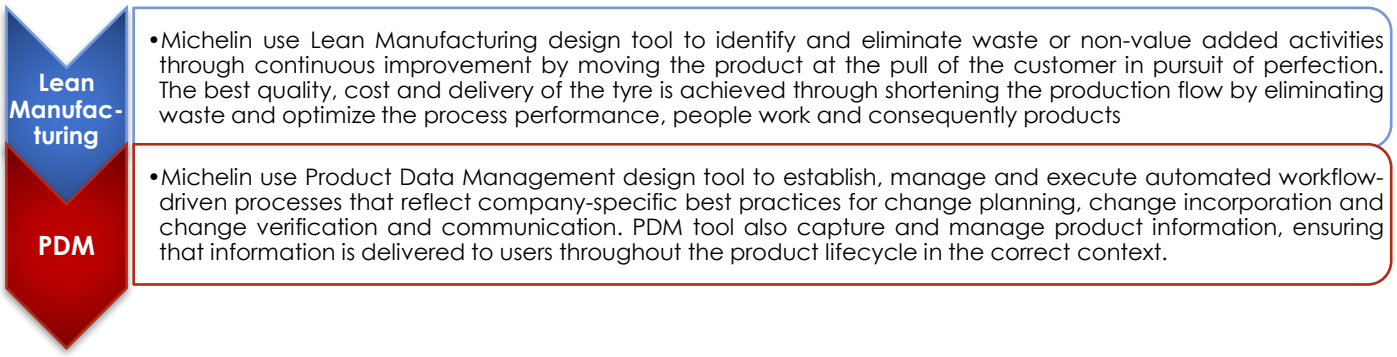


Figure 18 – Tools used in detail design, testing and refinement and production ramp-up phases

4.3 Design Process Unit

As shown on QFD analysis, the tyre has a lot of components that are related with the product requirements. In order to develop a product that fulfill its requirements using the company resources in the most suitable way, it is necessary to create a design strategy. To achieve this, a Design Process Unit – DPU theory will be used to perform a DPUs map.

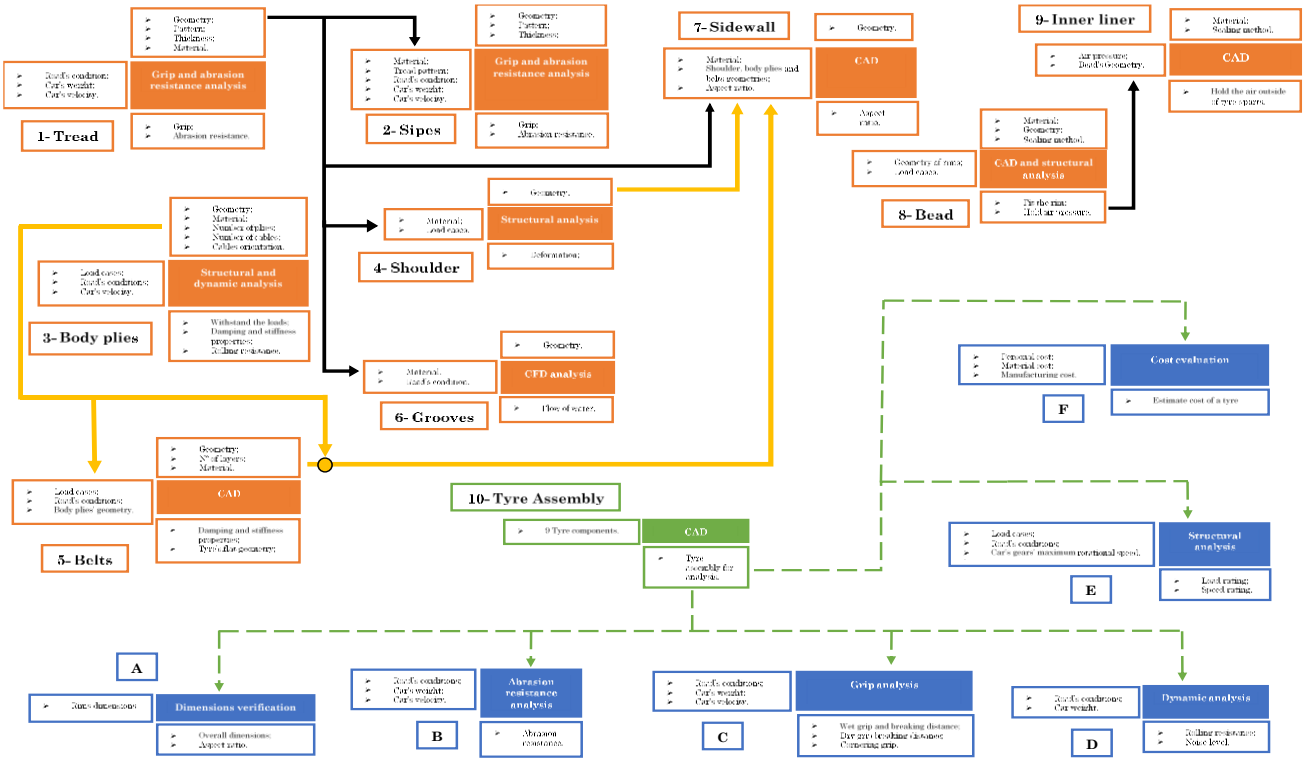


Figure 19 – DPU Map – Appendices C

4.3.1 Design strategy

As shown on DPU map, the design strategy is divided in two big phases: Each component design and assembly analysis. This is very important because the tyre works as one. All its properties are related and dependent from the others, for instance, the damping and stiffness properties are very related with body plies and belts but when everything is assembled, the overall damping and stiffness will be slightly different. Other important thing are the scenario specifications that comes from Michelin's database, these ones are not related with tyre's design specifications.

The design strategy is based on each component's influence on product requirements:

1. The tread is the component with more influence in the product requirements as shown in House of Quality and that's the reason why it is the first one to be develop. In this phase doesn't exist any design constraint which is good to have more freedom to develop the best possible tread just taking in account the scenario specifications. This design can need research activities first as a way of innovation and real improvement on the most important part of the tyre. In the end of this phase the tread's geometry, pattern, thickness and material will be defined to maximize grip and abrasion resistance;

2. The sipes are the second component with more influence on the product requirements. Besides, it needs some inputs from the tread since it is made from the same material (material input) and its pattern needs to be combined with the tread pattern (pattern input). In the end of this phase the sipes' geometry, pattern and thickness will be defined to maximize grip and abrasion resistance;

3. Like the tread, the design of body plies has completely freedom since it doesn't have any dependence relation with other components or any design demand. In the end of this phase the body plies' geometry, material, number of plies and cables and cables orientation will be defined to withstand the loads, minimize rolling resistance and improve the damping and stiffness properties to reduce noise and improve ride comfort;

4. The shoulder is made from the same material as tread so the only thing that is develop in this phase is its geometry, so it can control the tyre's deformation;

5. The belts receive as input the body plies' geometry that will give some specifications for the belt's geometry since they must fit one in the other. In the end of this phase the belts' geometry, number of layers and material will be defined so it can guarantee a flat geometry to improve tyre's contact with the road and improve the damping and stiffness properties to reduce noise and improve ride comfort;

6. The grooves are made from the same material as the tread so the only thing that is develop in this phase is its geometry to maximize the flow of water under the tyre;

7. The side wall receives as input the shoulder, body plies and belts geometries that will give some specifications for the side wall's geometry since it must guarantee the aspect ratio of the tyre too. The material is equal to the tread's material, so this is already defined. In the end of this phase the side wall's geometry will be defined;

8. The bead doesn't have any design constraint, but its geometry needs to fit to the already existing rims on the market and hold the air pressure;

9. The inner liner geometry is equal to protective cage for the bead's geometry. The inner liner material and sealing method needs to be defined so it can hold the air outside of tyre's parts.

10. Assembly of all components to create a tyre. Now is possible to run analysis to obtain more accurate results for the real product. The assembly analysis is organized by priority from A to F based on their importance for product requirements.

Some of the design activities as well as the assembly analysis can be made in parallel, that will only depend on the organization of the company's resources to this product. Without the necessary time for each activity, a simpler PERT – Program Evaluation Review Technique is shown to organize the design strategy in a more time effective way.

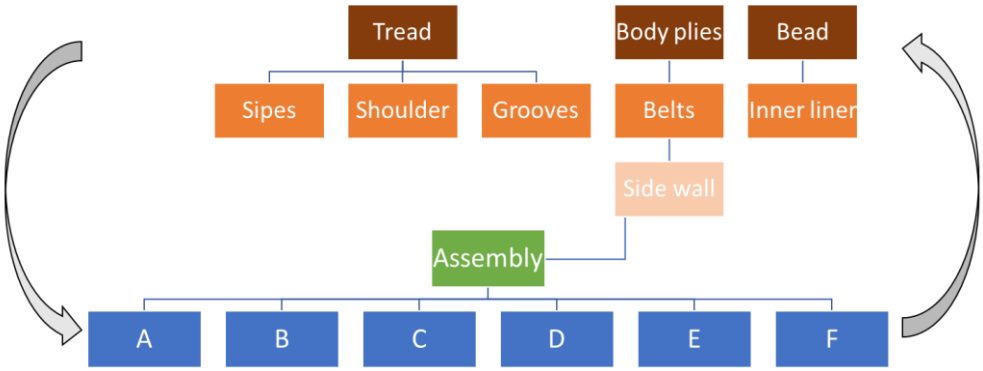


Figure 20 – Parallel design strategy

The DPU map was a great help to develop a good design strategy but, besides that, it will be also very useful to develop a control and evaluation plan for the product.

4.3.2 Control strategies based on DPU

In the end of each analysis will be possible to compare the tyre performance in some requirement with the specific target (when it exists) or with the other companies' tyres to know if is necessary to go back to some previous phase or not. This will be very useful in order to reduce the number of prototypes produced and to reduce the delay between the detection of a "problem" and the work for solve it since is way faster to run some analysis instead of constructing a prototype and test it. Although, since the analysis just starts when the tyre assembly is complete, a lot of time is wasted if all the analysis are made in series, even if all the changes are only made in the end of all of them instead of being made every time a "problem" is found.

As shown in figure 8, to be more time effective, is very important to run the analysis in parallel and decide all the necessaries changes after obtaining the results of all of them in order to allow everyone to work at the same time again, if necessary.

4.3.3 Set based concurrent engineering

Looking for DPU map or figure 8, is possible to see that the tyre assembly is a significant milestone for the whole project. If a lot of things need to be done again after the analysis results, a huge amount of time is wasted. When an optimum component is being develop is possible to achieve different results for the same objective. So, in a tyre, where everything will work together, is necessary to evaluate almost until the end each one of these

possible solutions (Design A, B, etc) in the final assembly. Set based concurrent engineering is the type of approach that suits here because it will make the design process quicker since it will delay the selecting process while is suitable, instead of making early decisions that can become failed projects with rework necessity. Besides, "*Primacy 3ST*" is not the only tyre develop by the company, so, this approach will also contribute to the develop of knowledge and its sharing which will be very important for the company future.

4.4 Company's organization

4.4.1 Disciplines involved

Developing Michelin's "*Primacy 3ST*" tyre is a complex process that typically involves contributions of many disciplines. These disciplines include many teams working on the product from different departments i.e., marketing, product development and manufacturing.

During the product development:

- The **Market Research** team is responsible for the market economic analysis and competitors analysis as well as the customers' new needs and desires. This department is responsible for the decision of develop a new product or modifying a existing one.
- The **R&D** department is responsible intellectual property (IP) opportunities or constraints, technical specifications and other aspects vital to the development of a new product or existing product offering. They report their findings to the product engineering/design and product management groups. Their main task is to create new knowledge.
- The **Engineering & Design** department works closely with the R&D and Market Research teams to satisfy the goals of the product and design a solution that will meet the defined customers' demands. The group develops detailed product specifications, builds prototypes and continuously improves the design of the product until it is brought to market. Engineers and product designers must also ensure that the products they design can be manufactured in time and with good quality at a cost that will allow the company to turn a profit.

Combining the knowledge of different departments in the product development, determining the level of specialization, organizing the specialized subunits and providing integration mechanisms is the task of the managers in the organization.

4.4.2 Organizational structure

An organization structure facilitates the coordination and implementation of project activities in a company. The main purpose of Michelin's organization structure is to create an environment that promotes interactions among the team members with a minimum amount of interruptions, overlaps and conflicts.

Michelin as an organization practices **Matrix Based** organization structure to support all the development activities of the different projects of its product portfolio. In the matrix based project organization, different programs are concentrated on their specific competencies and all the projects are provided with specialized staffs throughout the organization.

Michelin's aim is to utilize its resources effectively by allocating them in parallel running projects in different programs. Matrix based project organization also helps the team

members to share the information faster across the boundaries, gain knowledge of different departments and specialize or increase the depth of knowledge on particular topic. Team members are exposed to different program managers and project managers, which helps in the professional development and career progression of an individual. It is therefore easier to accomplish work objectives in an environment when tasks loads are shifting rapidly between programmatic unit.

The figure below, illustrates the matrix based organizational structure for 3 different projects of Michelin. "*Primacy 3ST*", "*Pilot Sport 4S*" and "*LTX M/S2*". These projects travel through marketing, product development, engineering and manufacturing departments during their development process. Each project is controlled by the respective project manager and different departments are controlled by the respective program manager.

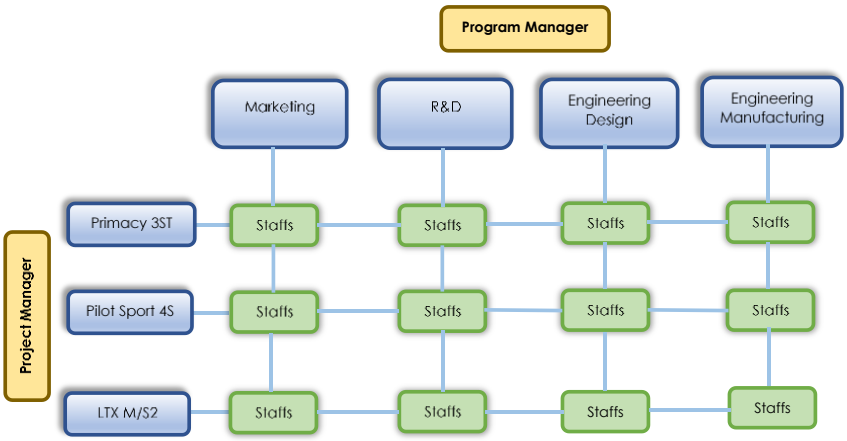


Figure 21 – Matrix based organization structure

4.4.3 Communication

In the development of an organizational structure, communication channels are an important consideration. The manager in a hierarchical system becomes a link in the communication chain. It is the hierarchical system that gives direction to and imposes restrictions upon the flow of communications. Management decisions flow from higher to lower levels in the organization while responses and reports flow upward. Therefore, we see from the outset that communications must function effectively in a lateral direction, as well as downward and upward. The figure below, illustrates the organizational chart in the product development phase.

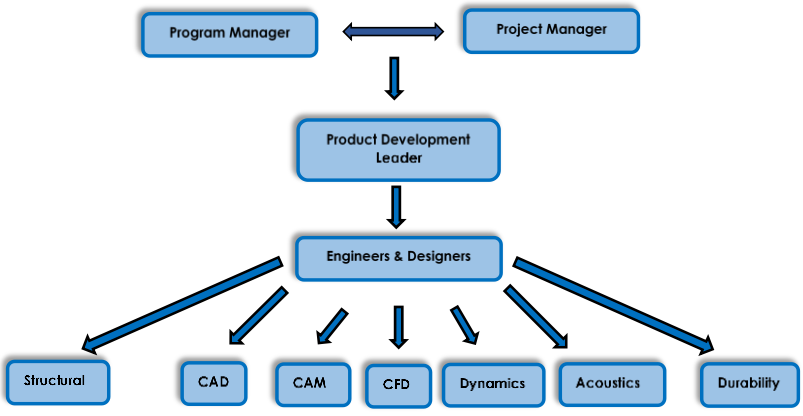


Figure 22 – Organization chart in the product development phase

The communication between different projects are represented in section 4.4.2 ***Organizational Structure***. As mentioned before, the matrix based organization structure provide a very convenient way of sharing knowledge between different departments and between different projects in the Michelin's product portfolio. Since the portfolio of Michelin includes different types of tyres, for different segments of the automobiles, the staffs get benefit of acquiring knowledge from other projects. The information flow for different components of the tyre can be observed in the figure 19.

As mentioned in the figure 14, Michelin uses Product Data Management (PDM) tool to document and manage all the product data and process related information in a single and central system. These product related data can be shared and used (based on hierarchy and permissions) by all staffs working on the project.

Once the project "*Primacy 3ST*" starts, Michelin arranges a meeting with the customer's surveys teams, program manager and project manager in order to develop the design process. This communication will be discussed with the Product Development Leader (PDL) and Product Manufacturing Leader (PML). PDL is responsible for all the product development activities and PML is responsible for all the manufacturing activities.

PDL and PML communicate to all the head engineers of different departments weekly. These head engineers are responsible to assign and monitor the tasks to their respective associates. All the progress, problems, suggestions, etc with respect to design and manufacturability will be communicated in the weekly meeting between PDL, PML, program manager and the project manager. The program manager and project manager are responsible for all the management activities linked with their field or project, respectively.

The great majority of communication will be guided through formal ***e-mail***, since Michelin believes that this kind of communication can provide sufficient proof if anything goes wrong in the development activities. Instant Messaging (IM) tools like skype for business are used to communicate between the staffs. This tool is essential to have meetings and screen sharing when people are working at distinct locations of Michelin. One of the characteristics of instant messaging is the ability to exchange real-time communication that will truly improve the velocity of communication.

6. PRODUCT AND PROCESS MONITORING

Lean development system is the base of Michelin's monitoring and action chain. An important pre-requisite of the continuous improvement process is the fixation of enterprise targets which can be controlled by KPI's – Key Performance Indicators. Company targets in product development, in general, may be subdivided in three main categories: effectiveness, efficiency and capability [11]. Effectiveness is related to "doing the right things", whereas efficiency means "doing things right". Capability can be seen as an enabler for the first two categories, staff and organization must be able to perform effectively and efficiently. Thus, in order to monitor the total performance of a project, a range of KPIs must be selected that covers all three categories of targets. In the next section, it is discussed why each KPI has been chosen, how it will be monitored and what actions are taken if the KPI is not met.

5.1 Key Performance Indicators

Engineer working time - *The total of man hours spent in engineering tasks.*

This indicator is used to validate if the design effort spent on the project is in accordance with the design plan and if similar design steps in product design processes conducted by the company before are being helpful to this project.

After each completion of a predefined design step, the total amount of engineering hours involved is measured. If it is found that the KPI is not met, it will be checked what was the cause of it. The engineers involved in the previous step are encouraged to comment on how these activities might be improved. All these improvement points are then listed and passed to the next design step. In this way, the design process can be continuously improved based on experiences from previous activities. The main objective here is to know if the engineers are lacking in knowledge and if some research activity should be done.

Project Schedule Variance (PSV) – *The difference between the scheduled and actual completion time of a project stage.*

In order to measure the compliance with the project planning, this KPI is introduced. It indicates how efficient a project stage is utilizing its scheduled time and thus helps indicating which parts of the project are not performing as well as they should.

In order to control project activities, the working time on each phase is monitored constantly and the PSV is calculated. When the KPI exceeds a certain threshold (for example, reaching 80% of the scheduled time), the employee responsible for the task will be asked if with the given allocation of resources, the task can be finished within the scheduled time. If not, this can be a motivation to assign more resources to the task or reschedule it.

Project stages that have exceeded the specified PSV will be used as activities to improve using a similar approach as discussed under the engineer working time.

Project cost variance (PCV) – *The difference between the scheduled and actual costs of a project stage.*

This KPI is used to measure the compliance with the project budget. It indicates how efficient a project stage is utilizing its assigned budget and thus helps indicating which parts of the project are not performing as well as they should.

In order to control project activities, the cost on each phase is monitored constantly and the PCV is calculated. When the KPI exceeds a certain threshold (for example, reaching 80% of the appointed budget), the employee responsible for the task will be asked if with the given allocation of resources, the task can be finished within the scheduled time. If not, this can be a motivation to reconsider the stage deliverables and allocate more resources, finish the activity later, evaluate if decreasing the quality still fulfilling requirements is possible, etc.

Project stages that have exceeded the specified PCV will be used in improvement activities using a similar approach as discussed under the engineer working time.

Ratio of redesign steps versus number of requirement changes – *The total amount of times that a designed component had to be started over from an earlier design step divided by the total amount of times its requirements were changed, summed over all components present in the design.*

This KPI is critical for assessing the effectiveness of the project. It indicates how many times designers had to redo their design while the requirements were unchanged, what would mean that they did not design the part right in the first time. It is important to note that this indicator will only include redesign steps that imply that for instance a new concept solution has to be chosen and detailed again and that iterative improvement of components is not regarded here.

Every time either a redesign step or requirement change happens, this indicator will be evaluated. Exceeding the performance indicated ratio for the project means that either concept solutions are badly worked out or wrongly chosen and thus more focus should be put on concept generation and selection. The design disciplines or stage responsible for the excessive redesign will receive extra support to come up with workable concept solutions. Besides, this can also occur due to lack of communication methods between the earlier phases and the design ones. For this, communication mechanism should be improved.

Percentage of ideas adapted from company's database – *The percentage ratio of times an idea/ concept/ solution is selected from the company database of design information versus the total amount of times an idea/ concept/ solution is created.*

A company working in tyre market in the last 128 years has gathered a lot of design knowledge about tyre components. To keep the team away from reinventing the wheel, it should be an objective to consider the knowledge available and reuse or adapt it to fit into the new project. This KPI can thus be used to track the effectiveness and efficiency of the design process and helps identifying waste.

Throughout each design phase, the number of design ideas is tracked, as is the number of times an idea from the company's knowledge base is adapted. After each phase, the KPI is evaluated using this numbers. If the indicator is not satisfactory, the decision can be made to redo some part of the previous design phase and focus on reusing data. Where this might seem as wasting time or rework at first sight, it can actually help in speeding up the design in the subsequent phases. This is because designing a component from scratch is often more time-consuming and error-prone than adapting or implementing a known and proven solution. Parallel to this, it should be identified why too limited data was reused and if this is caused due unavailability of data (lack of company's knowledge) or too little focus on reuse the previous projects ideas. This input can then be used to improve the data system, team training or start new researches.

Percentage of ideas stored in company idea database – *The percentage ratio of times a new idea/ concept/ solution is added to the company database of design information versus the total amount of times a new idea/ concept/ solution is created.*

In parallel with the previous KPI, for the contribution of individual design processes to the overall product development efficiency of the company, innovative ideas generated during the process should be reusable as well. Therefore, this performance indicator is introduced to embed this company target into the design process.

It is measured in the same way as the percentage of ideas adapted from the company idea database. Design engineers are encouraged to provide information about their ideas in such way it can be reused by additional staff training on this topic. This however should be balanced with the design tasks that mainly have to be fulfilled within the project.

Percentage of tasks performed by the company – *The percentage ratio of tasks that were successfully carried out by the company that were assigned to them versus the total amount of tasks.*

A successful project requires a design team that can fulfill the specified tasks. In order to monitor the team capability, this KPI is introduced.

An unsatisfying value for this performance measure indicates that the company resources are not being enough for what was planned. This can be caused by lack of team members, lack of available knowledge or too greedy initial plan. This is counteracted by properly training or assigning more team members if possible and outsourcing contribution if it exceeds in-house capabilities.

This requires periodic assessment of the KPI, for instance on a weekly basis, to address possible bottlenecks in time. If one would wait until a design phase is finished, the problem can become worse and more expensive.

7. DOCUMENTATION

Documenting your company's information is one of the most important internal tasks a company should undertake. One of the most important reasons for documenting any process is the fact that it reduces operational ambiguity. The next time there is a confusion regarding who is supposed to do what, what are the best practices for a task or what was really decided, it takes just a look at the detailed documentation and the dispute can be resolved.

These documents act as a store of collective organizational knowledge regarding the processes and can be accessed by anyone in times of need. The documentation also acts as training material to help trainees improving their learning process. Documentation can also be used by the marketing and sales department to truly understand the company's capabilities. This knowledge helps them to truly determine what they can promise to the customer and what can be fulfilled. With the process knowledge, the marketing department will be able to make business that the organization can fulfill. There will be no need for over and/or under promising which causes heartburn and turmoil amongst the customers at a later stage. Another important thing is the financial reports for example that can be of much use in further analysis.

In summary, documentation is important because without it, it is not possible to "pass" the past information for the future generations.

Michelin as an organization, continuously improving the documentation methods for product and process related to all the projects being carried in the company. Given below is the detail information on how documentation is carried out in the product development of "*Primacy 3ST*".

Documentation of product related information:

As mentioned in the previous sections 4.2 and 4.4.3, PDM tool is used to document the product related information in Michelin. PDM tool provides the necessary information on company's portfolio on different products which are related to "*Primacy 3ST*" tyre. For any project it is not possible to make everything with new technologies and knowledge during the developing phase, since most of the information will be taken from the previous projects. Modifications will be done to the data that suffer "innovation". By considering the data of previous version of "*Primacy 3ST*", new changes in the project is documented in the PDM for further use or development process.

Documentation of process related information:

All the project kick-off meetings, meetings related to the development of product at different hierarchical structure of project will be documented for further reference. These meetings related to the product development process will be documented as Engineering Change Order (ECO) or Engineering Change Request (ECR). Any meetings in the lower hierarchical organizational structure will be documented under ECO in PDM tool. Any meetings in the higher hierarchical organizational structure will be documented under ECR in PDM tool. Documentation under ECR is very rare and critical, as this documentation refers to the changes in the design processes of the product due to the problems faced during manufacturing of the product or changes in the initial demands. Documentation under ECO is due to the changes in the design processes during the initial phases of the product development.

In general, Documentation in Michelin will be carried out in all the phases of product development and can be documented in a common data base called PDM tool. These documentations can be accessed by each and everyone in the organization, but authority to modify the documentation will be limited to authorized personnel's in the organization.

8. Conclusion

The case discussed in this report was the design process of "*Primacy 3ST*" tyre of Michelin. Since the company is already present in the current "Passenger car and Light Truck & Related Distribution" market, a performance analysis was made where it was concluded that Michelin's does not have anymore the best tyre of that segment. Voice of Customers took a very important role here as the starting point. The requirements and wishes of the customers were clear and together with the company and legal standards, they formed the input of the starting point of the design process. The QFD and DPU give more insight in the importance of the different components and where the interfaces of the components are during the design. With this, the KPIs forms a starting point of the control of the design process. All documentation and communication processes are very important for the project and company to improve the quality of the present and future products. In brief, this report forms a guideline for Michelin's design process of their new series of "*Primacy 3ST*".

9. References

[1] Michelin website: www.michelin.com
[2] Michelin Group Headquarters, Michelin Performance and Responsibility, June 2012
[3] Michelin Group Headquarters, An Extensive Brand Portfolio, 2016
[4] Dr. Anke Blume, Plastic and Elastomer Engineering lectures, 2017/2018, University of Twente
[5] Michelin Group Headquarters, Annual report, 2017
[6] Robert G. Cooper and Angelika Dreher, Voice-of-Customer Methods
[7] Dr. Ir. Juan Jauregui-Becker, Modelling of Technical Design Processes lectures, 2017/2018, University of Twente
[8] Mark V. Martin, QFD and the designer: lessons from 200+ houses of quality, Stanford University
[9] T. Tomiyama, Design methodologies: Industrial and educational applications, 2009
[10] J.M. Jauregui-Becker, Knowledge structuring and simulation modeling for product development, University of Twente, 2012
[11] U. Dombrowski, K. Schmidtchen, and D. Ebentreich, Balanced Key Performance Indicators in Product Development, *International Journal of Materials,* 2013
[12] Durward K.Sobek ll, Toyota's Principles of Set-Based Concurrent Engineering, 1999
[13] Dag Raudberget, Practical Applications of Set-Based Concurrent Engineering in Industry, Journal of Mechanical Engineering, 2010
[14] V. Krishnan, Product Development Decisions: A Review of the Literature, *The University of Texas at Austin, 2015*
[15] Website: www.en.wikipedia.org/wiki/Tire_manufacturing
[16] Website: www.michelinman.com/US/en/help/how-is-a-tire-made.html
[17] Website: www.oponeo.co.uk/tyre-article/tyre-construction-functions-of-individual-elements
[18] Website: www.smallbusiness.chron.com
[19] Website: www.tyres.cardekho.com
[20] Website: www.managementstudyguide.com/documentation-of-process.htm
[21] Website: www.lucidchart.com/pages/process-documentation
[22] Website: www.isixsigma.com/tools-templates/kano-analysis/designing-profitable-products-using-qfd-and-kano-model/
[23] Website: www.isixsigma.com/tools-templates/kano-analysis/designing-profitable-products-using-qfd-and-kano-model

Appendices

A. Michelin's sustainability analysis

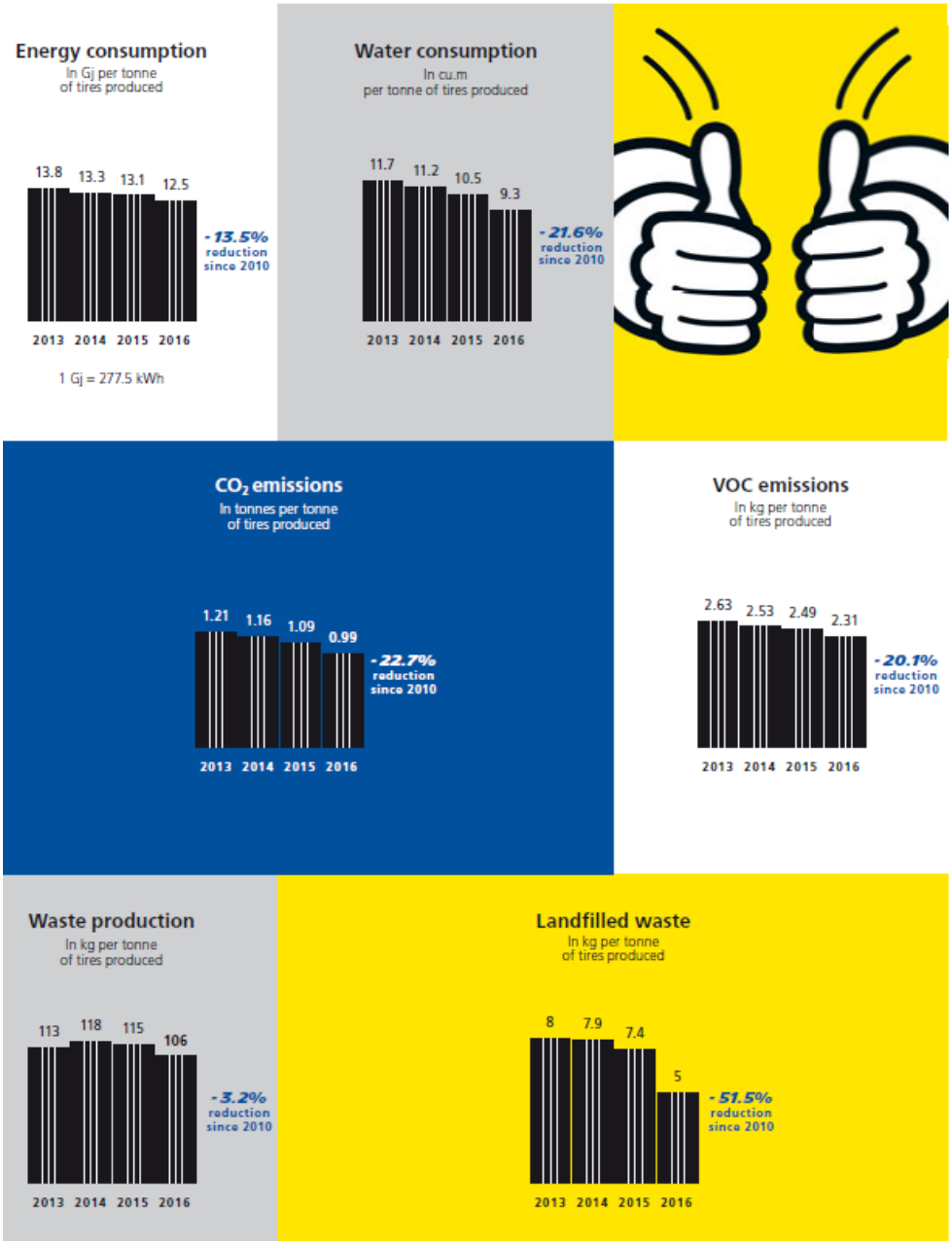


Figure A.1 - Reduction on environment impact, [5]

B. Economic analysis

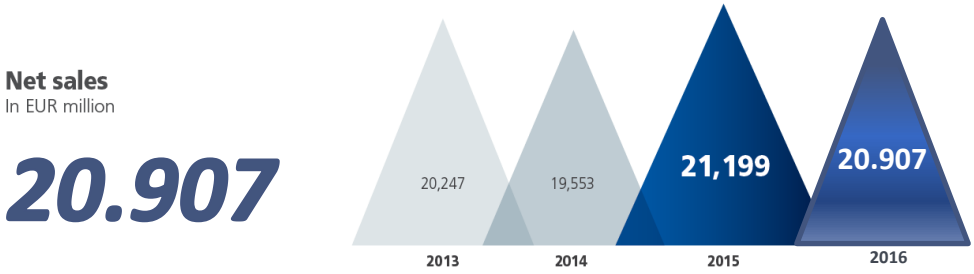


Figure B.1 – Net sales evolution between 2013 and 2016, [3] and [5]

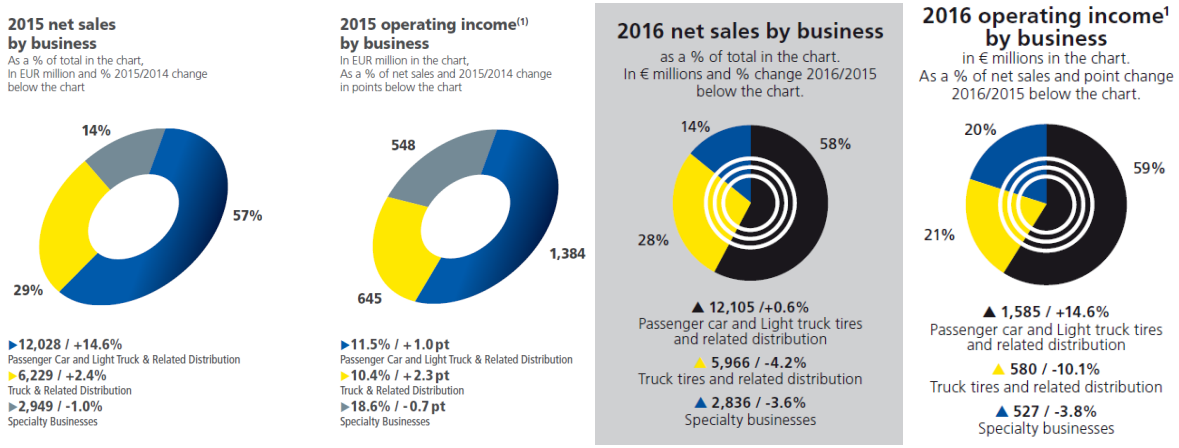


Figure B.2 – Net sales and operating income by business in 2015 and 2016 graphs, [3] and [5]

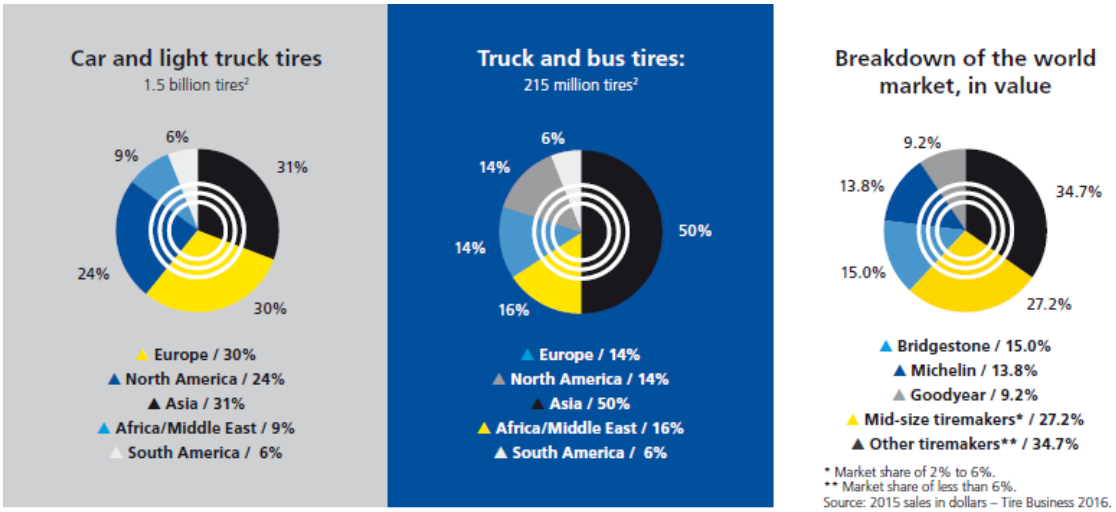


Figure B.3 – Company's sold tyres per area and world market division 2016, [5]

C. DPU Map with better visualization

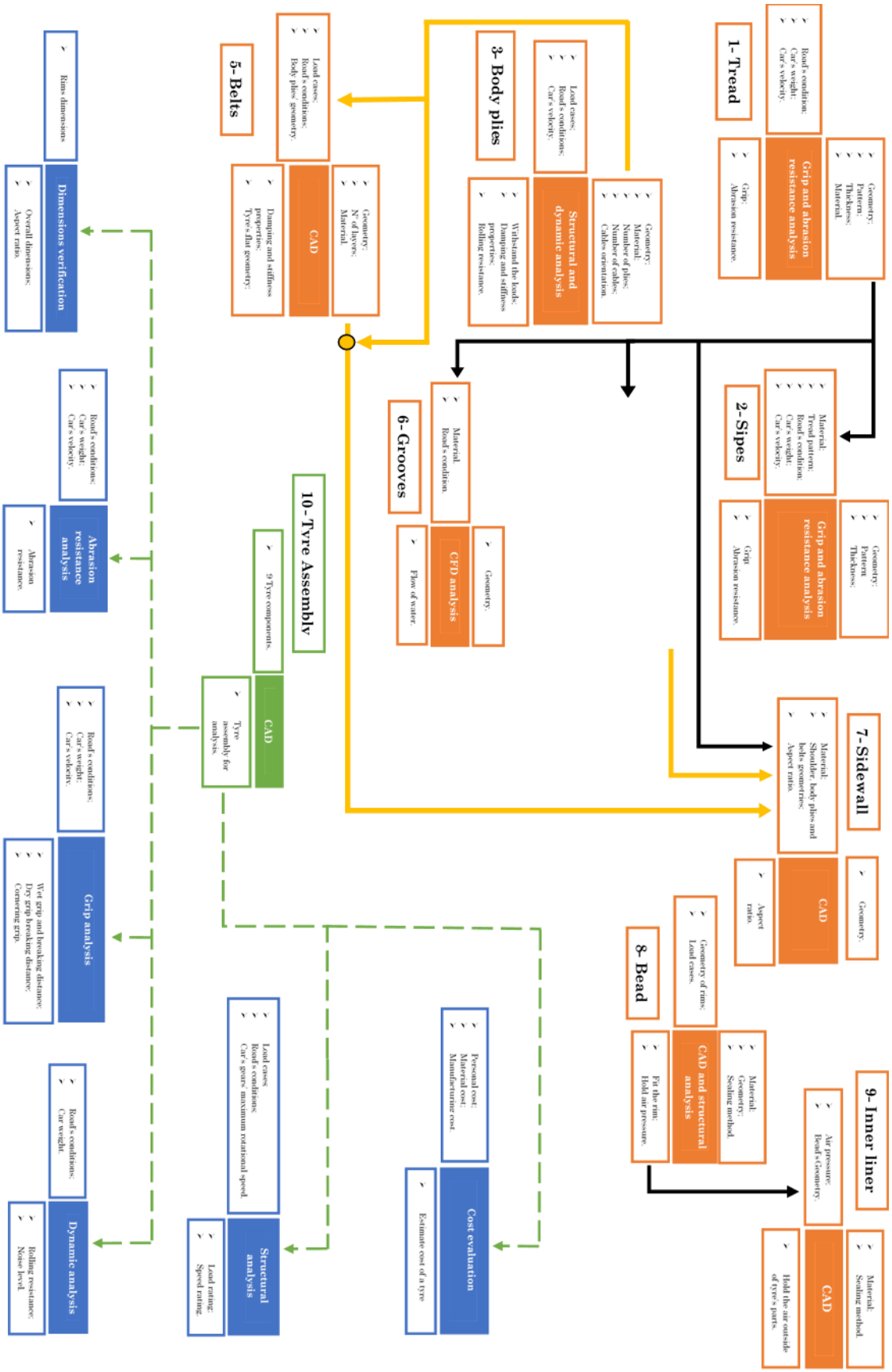


Figure 23 – DPU map