POLITECNICO DI TORINO

Master Degree course in Engineering & Management

Master Degree Thesis

The impact of the development of a new modular product on company strategy

Sabelt GT-PAD racing seat case

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A mia madre e mio padre, per essere le guide della mia vita.

Summary

In an increasingly competitive and segmented global marketplace, the need to diversify is greater than ever before. Advances in production technologies has rendered out many of the differences in product quality and thus changed the competitive environment companies find themselves in. Traditional mass production has in the past decade been replaced by the concept of mass customization or mass production of customized products. To overcome the great complexity that customization potentially creates in the manufacturing systems, modularization is used as a tool to break the product structure into smaller and manageable units. For these reasons, the aim of this thesis work is to explain the application of new product development process methodology on a new modular racing seat, called GT-PAD, being part of project portfolio of Sabelt SpA. GT-PAD seat will be explained following product planning, concept design, detailed design, test & prototyping and process design phases, with an always present project management background during the entire development. The GT-PAD new product development is the first part of the thesis work, followed by a complete analysis on company resources, capabilities and strategies owned by the company and how they change in relation to the introduction of a new project like this.
In conclusion the work aimed at identifying a number of strategic advantages or disadvantages given by the introduction of a modular product development project inside a company portfolio and in which way a new product development process can be conducted in the most appropriate way possible.

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Chapter 1

Introduction

The locus of corporate innovations has been product development. But in times of rapid and unpredictable change, the creation of individual products becomes less important than the creation of a general organizational aptitude for innovation.
(John Seely Brown, Deloitte's Co-Chairman)

New products, new markets, new investors, and new ways of doing things are the lifeblood of growth. And while each innovation carries potential risk, businesses that don't innovate will eventually diminish.
(Adena Friedman, NASDAQ OMX CEO)

As John Seely Brown said, in the last decades new product development process found a deeper focus from companies. What is true is that, beyond new product development centre of attraction, also organizational chart, company's structure and strategic vision should be taken in account, as direct consequence of products development itself. Taking in consideration Innovation Research Interchange (IRI) global 2018 R&D trend forecast article published at the beginning of the year ([28]), R&D spending expectations will climb again in 2018 respect to 2017, respectively 59% of respondents expects an increase in R&D expenditures, 29% anticipating little or no change while only 12% are expecting a decrease in total spending. Also the article published by Standard & Poor's at the end of 2017 ([18])confirms growth forecast: for 2018 European R&D expenditures will raise of 2-3 %, thanks to the European development of a steady economic environment, with a GDP growth year-on-year of 1,9 % in 2018 and 2019, unemployment rate declination and accommodative financing conditions.
As a global insight, we can conclude that New Product Development (NPD), as a direct consequence of R&D expenditure, has become of central importance for companies all over the world. The automotive sector shows up as less attractive or less lucrative place to invest than other industries: for this reason little tricks are necessary for becoming competitive globally[36].
The ways through which competitive position can increase are:

- **Share platforms and manufacturing** - this point is the most important for this paperwork. GT-PAD seat shares platforms within the other seats produced by the company and R&D expenditures, allowing cost savings in material procurement and in excess capacity reduction;
- **Short product cycles** for obtaining higher R &D development rate and vehicles that can be adjusted to changes in the marketplace more frequently;
- **Innovation capacity** implied as a combination of R&D and non-R&D factors (e.g., creativity, connectivity, business models)

For all these reasons, the aim of this thesis is to analyse new product development process of a modular product inside a company project portfolio and how it affects resources, capabilities and strategies of the company itself.

1.1 Theoretical background

In order to explain completely the huge process of a new product development, Resource-Based-View RBV basic theory, core competencies and competitive advantage knowledge will be used. For analysing the corporate strategy of Sabelt company and how the development of a new product affects its resources and capabilities, strategy and organization knowledge, innovation management and new product development tools are applied, quality engineering learnings will be used, obtaining a clear framework of the company and of the work done.
Theoretical background study has been conducted in parallel on two different matters: on one side New Product Development features have been discussed, on the other side company's strategy and its subsequent positioning has been analysed. Two major books have been consulted: *Management of innovation and product development* of Cantamessa M. and Montagna F. and *Strategy & Organization* of Neirotti P., together with other books such as *Product design and development* of Ulrich K. and Eppinger S. and *Strategic management of technological innovation* of Schilling M.

1.2 Research objectives

The aim of the thesis is to analyse the new product development project of a new racing seat born as a new project inside the program management schedule of Sabelt SpA. The seat - GT-PAD is its name - is the first Sabelt's modular seat: this means that the shell, made by fibreglass, can be covered by different pads of diverse size and colors. It has been conceived across all the departments of the company and will be explained using mainly the new product development tools learned during the 'Innovation management & new product development' course followed during the last year of my master degree, adding also all the related knowledge learned in other courses of the Bachelor and Master Degree.
The objective of the research is, rather than applying only theoretical concepts learned during my studies, to propose a real insight into NPD process, obtaining a product that it is currently selling on 2018 company's sales catalog. The analysis will also focus not only on the project but also on the major departments involved in the R&D process.
Consequently, the aim of the paperwork is to manage also company's resources and capabilities affected by the new project and moreover, the thesis aimed at analyzing

how the development of a modular product affects the already existing strategy of the company.

1.3 Thesis structure

The thesis shows every single step regarding the new product development process and how it affects internally company's resources and capabilities and consequently its strategy. Chapter 1 is dedicated to introduction, chapter 2 lays the foundations for project portfolio management tools. From the third chapter every phase needed for the seat development process starts: chapter 3 shows in product planning, chapter 4 concept design, chapter 5 prototyping & testing, chapter 6 process design. Chapter 7 examines the resources and the capabilities of the company before and after the project and how they are affected by the project itself and shows in details all the modularization strategies that exist in theory and how the product modularity affects the current strategy of the company. The final chapter shows the conclusions regarding company strategies and how they are changed after the modular product development. Glossary and bibliography give the end to the entire thesis.

Chapter 2

Project Management background

Project Portfolio Management (PPM) is a key area of the Project Management literature. Project management *stricto sensu* deals with individual projects at operational level, while program management deals with programs, or clusters of related projects, at a tactical level. Finally, project portfolio management copes with the strategic decision on which projects and programs should be initiated: historically the way through which projects are chosen shows a bottom up approach.
It is not uncommon for companies to be quite unaware of their R&D portfolio: as a consequence, a firm that does not use PPM correctly will also find it difficult to terminate unsuccessful projects when it becomes clear that the desired results are not emerging, and to do so before costs become too high. A robust PPM system so it is necessarily conceived based on three pillars:

- Project categorization;
- Project evaluation through specification;
- Use of decision making tools.

When dealing with R&D activities, the first element to be recognized is that projects are not all the same: they differ along a number of dimensions, such as risk, project size and project scope. As a first cut, it is possible to divide projects in finer subsections. In the case of Sabelt company, its projects have been categorized as in the table (2.1).
Dealing with basic or applied research projects is different because they are project with different objectives: the former have "maintenance" R&D objectives, with the purpose of ensuring the survival of the firm and keeping up its competitive advantage, the latter show a "growth" in R&D objectives, aimed at upgrading the firm's competencies by mastering a new technology or looking for technological breakthroughs. Platform development projects are born as a collection of technological assets that are proven to work together and they serve as the basis for developing a family of multiple derivative products: in Sabelt case the Dallara Stradale project is born as a project aimed at developing a platform, inside the prototype department, for car kits saddling. Car kits are in fact mere replication of a standard one, in different colors and stitchings.

The product development projects aimed at launching a specific product addressed to a given market segment: this is the aim of this thesis because GT-PAD is a product that will be sold on the 2018 catalog. However, GT-PAD is also part of customized projects section because it has the objective of adapting an existing product - or substituing it (and in our case the GT-300 seat will be replaced) - to the needs of specific customers (and in our case customers are mainly Renault and Ferrari).

Basic research	**Applied research**	**Platform development**	**Product development**	**Customized projects**
Ferrari Challenge	McLaren P14	Dallara Stradale	Abarth 124	GT-PAD
Ferrari GT-458	McLaren P15	Hyundai TCR	Michelotto GT2	Ferrari Corse Clienti
Ferrari GT-488	Thales Alenia Space	F1 belts	Michelotto GT3	Ferrari 70th anniversary
			Renault Rally Cup	Hyundai Rally R5

Table 2.1: Sabelt's Project Portfolio

The project portfolio selection process inside Sabelt has a bottom-up approach: projects are proposed by corporate functions and selected according to their inherent viability and compliance to strategy. The bottom-up approach is easier to implement and leaves more creative freedom to the lower ranks of the organization, which are closer to the needs of business operations and to market requirements.
For better understanding GT-PAD project it should be analysed all the New Product Development process theory and, using the resource-based view theory of the firm, also the sets of resources and routines that characterize it.
The NPD process will be significantly different from firm to firm and will depend on the industry, on the products being developed, on the upstream and downstream relationships with other firms and, of course, on firms' past history. However in general, new product development process is characterized by the following phases:

- **Product planning** is the initial phase of the product development process. In this phase the firm has the objective of defining the new product perspective of market and technology. It aims at defining strategic decisions about which markets and which segments should be explored and it reflects also about which resources, internal or to be acquired, will be used. Product planning is so a highly interfunctional and interdisciplinary phase, connecting marketing, sales, R&D, design and corporate finance functions.

- **Concept design** is the first time in which technical solutions should be chosen, defining in this way the product concept. Given the product concept, the firm will draft detailed technical specifications that will provide designers involved in the subsequent steps with a clear idea of the functions and performance levels that the product will have to achieve. In this phase R&D, design, production, sales and marketing departments are involved.

- **Detailed design** is the phase where most of the engineering work is carried out. Detailed design activities involved choice of final technical solutions, study of interfaces, choice of materials, choice of suppliers and consequent evaluation of time and costs. The company functions involved in this phase are R&D, design, production & maintenance and purchasing.

- **Prototyping & testing** deals with verifying and validating detailed design phase. Testing can be performed analytically, through simulation or on physical prototypes and can be repeated several times during development process.

- **Process design** involves designing a large number of the resources required by such processes, such as tools, dies and fixtures for manufacturing, service manuals and tooling for field engineers. R&D and Design, production & maintenance and purchasing are involved in this last phase.

- **Product launch** is the last phase of product development process. After launching, market feedback drive product review towards an always improving mechanism.

The original Gantt chart, according to the theoretical phases of NPD process, for the new GT-PAD seat is illustrated in the figure below:

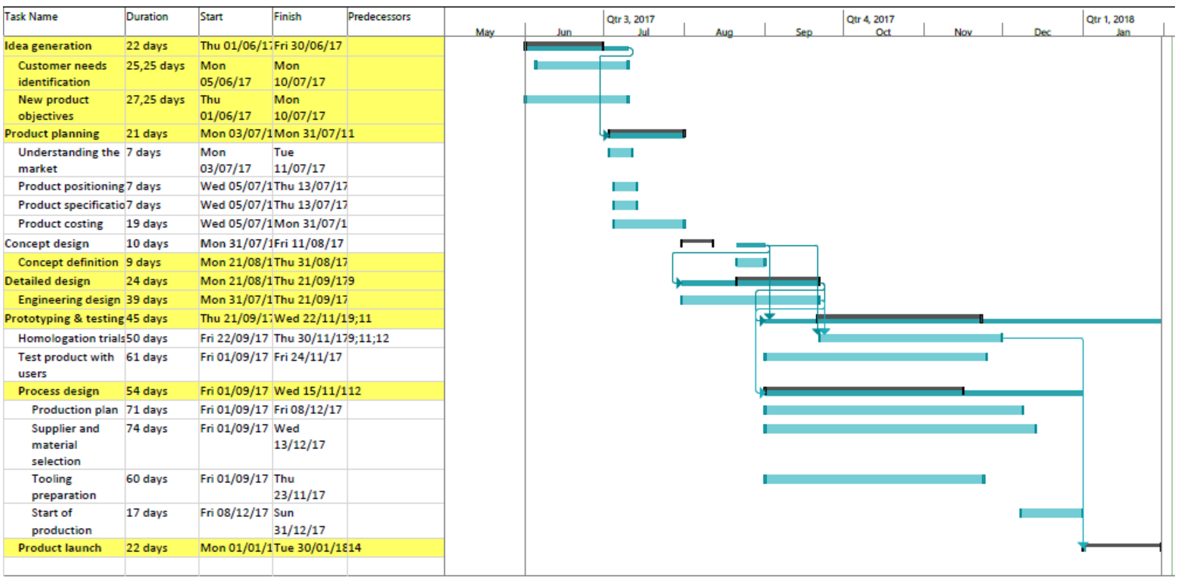


Figure 2.1: Original Gantt chart

In total, the product development process lasts for 7 months, from June to December 2017, in order to launch definitively the product on the market at the beginning of 2018. The task in yellow are the critical ones which have been taken in account with specific attention. The product launch phase is not really critical, because it starts the 1st of January and it is still ongoing but for Gantt computation an end of this task has been stated. The most critial parts of the project so are the idea generation and the concept and detailed design, due to the fact that they are affected by several changes during the product development process itself.

2.1 New Product Development management issues

In order to evaluate the project feasibility before starting a deeper treatment of the matter, it should be noticed that best practices suggest combining hard financial elements together with soft and qualitative ones. Moreover, also the original Gantt chart will be analised and several differences will be found. This insight suggests making a combined use of financial and multicriteria ones for the feasibility study: financial methods have been used to perform a preliminary screening of candidate projects while multicriteria methods have been used to refine the selection by assuming a broader perspective.
Regarding financial methods,in case of product innovation, any innovation project involves the investment of financial resources, in the expectance of future returns, which will generally be in terms of margins from sales. Therefore, project selection must take into account financial aspects: the simple Net present Value indicator (NPV) needs of an high computational effort and often firms tend to use Payback Time (PT) instead, but Payback Time does not take in account about discounted cash flows, leading towards a strong bias estimation. It is generally quite difficult to make a proper use of financial methods, especially because when evaluating marginal cash flows, one should not consider sunk costs in its computation. We should say that projects should not be considered in isolation, but in aggregate. This is important because projects compete for resources that are scarce and generally hard to reproduce. For this reason, the real cost of a project is not simply the accounting cost involved but the opportunity cost of the greater value that could be gained if the project were not activated, thus allowing free resources to work on another one. An easiest approach is the Expected Commercial Vale ECV that consists in estimating project-specific technological success P_t and commercial success P_c, coupled with development cost DC and the production and launch cost CP. Moreover, ECV consider also NPV inside its formula, in fact:

$$ECV = (NPV \times P_c - CP) \times P_t - DC \tag{2.1}$$

Plugging numbers, cash flows for GT-PAD project are illustrated in the table 2.2, obtaining thus a NPV of €184 780,25, using a discount factor of 10% and considering an initial investment with the supplier of €50 000. The initial investment used as CF_0 of 50 000€ is the value of the contract with the italian supplier with has tunisian facilites (more about production plan will be explained after).
Concerning revenues, the expected volumes of sales and the related cost for shells and kit pads respectively are shown in the table below: because the product is modular (i.e. this means that you can by the shell and then personalize it with different size and colors of kit pad) volumes and costs are split because they can be bought together or separately.

	Year 1	Year 2	Year 3	Year 4	Year 5
Kit pad [nr]	280	300	320	340	360
Shell [nr]	250	265	280	295	310
Kit pad cost [€]	44	46	48	50	53
Shell cost [€]	250	255	260	265	270

Table 2.2: Volumes and costs forecast over 5 years

Obviously the number of kit pads is higher respect to shells thanks to modularization concept. It's the market itself that drive the volumes of kit pad and shell in a different way: according to first orders coming for GT-PAD seat, the trend of volumes is less for shell but accompanied with a positive trend for kit pads, demonstrating that modular concept is sales-driving and a lot appreciated by customers.
The price of kit pad is 140€ for the normal kit or 148€ for the customized one, obtaining an average price of 144€; the shell instead is sold at 465€. COGS is obtaining summing the cost of kit pads and the cost of shells for their relative sales volumes; payroll expense instead is calculated considering that the GT-PAD is developed inside Sabelt SpA, using one resource for 1 hour at week for one year at the cost of 40€/h but it is produced in Tunisy, producing 3 shells at week spending 10 hours per day at the hourly cost of 10€ (10€ is the cost that Sabelt pays for tunisian workers: in practice they are paid 4€/h). Other expenses, such as supplies, repairs and maintenance, advertising, utilities and insurance have been extracted from Sabelt financial accounting 2017 closure (confidential).

Enter Company Name Here	Sabelt SpA - GT-PAD project					
Enter Date Here						
	Pre-Startup	Year 1	Year 2	Year 3	Year 4	Year 5
1. CASH ON HAND						
[Beginning of month]		-	22.145	44.390	66.495	88.244
2. CASH RECEIPTS						
(a) Cash Sales		156.570	166.425	176.280	186.135	195.990
(b) Collections from Credit Accounts						
(c) Loan or Other Cash Injection						
3. TOTAL CASH RECEIPTS						
[2a + 2b + 2c=3]	-	156.570	166.425	176.280	186.135	195.990
4. TOTAL CASH AVAILABLE						
[Before cash out] (1 + 3)	-	156.570	188.570	220.670	252.630	284.234
5. CASH PAID OUT						
(a) COGS		74.820	81.375	88.160	95.175	102.780
(b) Gross Wages (excludes withdrawals)		17.680	17.680	17.680	17.680	17.680
(c) Payroll Expenses (Taxes, etc.)		1.768	1.768	1.768	1.768	1.768
(d) Outside Services						
(e) Supplies (Office and operating)		5.000	5.000	5.000	5.000	5.000
(f) Repairs and Maintenance		1.500	1.500	1.500	1.500	1.500
(g) Advertising		1.000	1.000	1.000	1.000	1.000
(h) Auto, Delivery, and Travel		10.000	10.000	10.000	10.000	10.000
(i) Accounting and Legal						
(j) Rent						
(k) Telephone						
(l) Utilities		4.000	4.000	4.000	4.000	4.000
(m) Insurance		3.000	3.000	3.000	3.000	3.000
(n) Taxes (Real Estate, etc.)						
(o) Interest		15.657	18.857	22.067	25.263	28.423
(p) Other Expenses [Specify each]						
(q) Miscellaneous [Unspecified]						
(r) Subtotal	-	134.425	144.180	154.175	164.386	175.151
(s) Loan Principal Payment						
(t) Capital Purchases [Specify]						
(u) Other Start-up Costs						
(v) Reserve and/or Escrow [Specify]						
(w) Owner's Withdrawal						
6. TOTAL CASH PAID OUT						
[Total 5a thru 5w]	-	134.425	144.180	154.175	164.386	175.151
7. CASH POSITION						
	-	22.145	44.390	66.495	88.244	109.083

Figure 2.2: Cash flow analysis over 5 years GT-PAD project

Stating finally a project-specific technological success $P_t = 0.75$ and commercial success $P_c = 0.90$, using as development cost DC the total cost of design and engineering of the product (estimated using Sabelt 2017 financial account) = € 65 000 and with an expense for launch CP = € 25 000, the ECV of the GT-PAD is equal to:

$$ECV = (184780{,}25 \times 0{,}9 - 25000) \times 0{,}75 - 65000 = 40976{,}67 \tag{2.2}$$

showing that the project is valuable and has potential success in the market.
Multicriteria methods instead are based on qualitative data, and in our case, it has be chosen to use mapping methods to compute the division of budgets among the basic research, applied research, platform development, product development and customized projects listed in table 2.1.

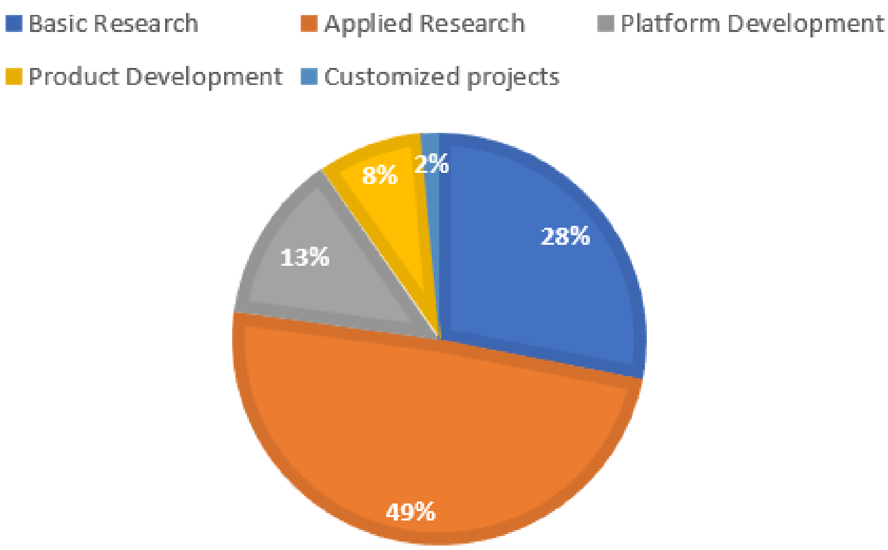
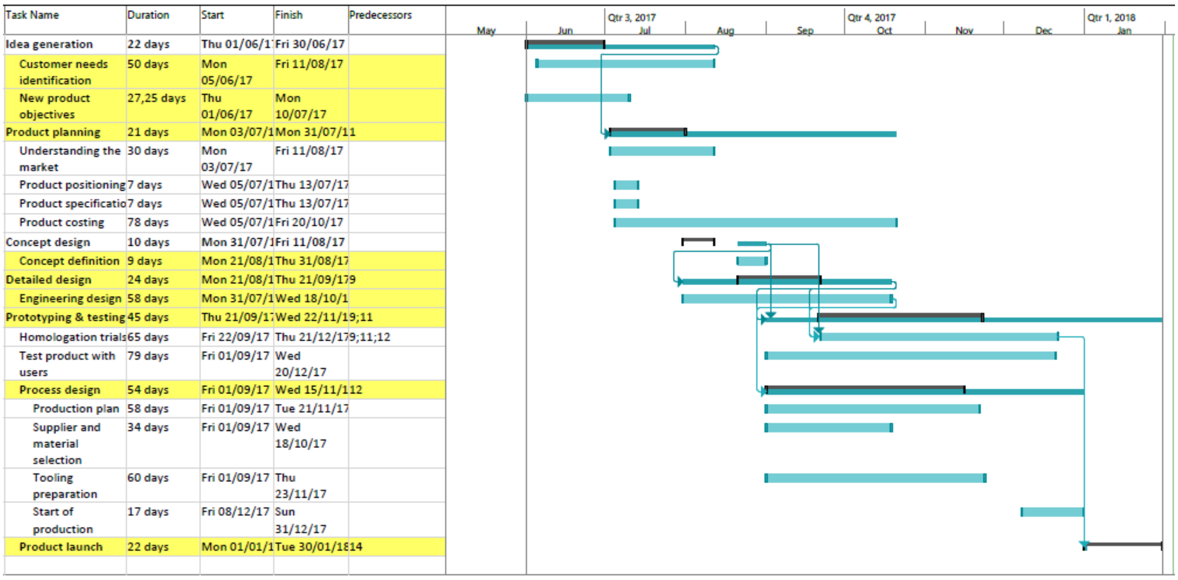


Figure 2.3: Sabelt projects budget allocation

As it is shown in the graph, customized projects profit of a little part of the budget but the profitability of these projects is high, due to the fact that they use material and resources that have been already allocated to other projects but thanks to customization they have an higher value added for the company. GT-PAD is part of customized projects but take also part of product development projects: in this way resources of R&D departments could work exploiting different budget allocations for a broader objective.
Finally, considering the original Gantt chart established at the beginning of June 2017, the effective project then showed several differences. The real development of the GT-PAD in fact shows the presence of iterations during prototyping phase and during idea generation and detailed design definition.

In fact, the real Gantt chart is illustrated in the figure below:



Task Name	Duration	Start	Finish	Predecessors
Idea generation	22 days	Thu 01/06/1	Fri 30/06/17	
Customer needs identification	50 days	Mon 05/06/17	Fri 11/08/17	
New product objectives	27,25 days	Thu 01/06/17	Mon 10/07/17	
Product planning	21 days	Mon 03/07/1	Mon 31/07/1	1
Understanding the market	30 days	Mon 03/07/17	Fri 11/08/17	
Product positioning	7 days	Wed 05/07/1	Thu 13/07/17	
Product specificatio	7 days	Wed 05/07/1	Thu 13/07/17	
Product costing	78 days	Wed 05/07/1	Fri 20/10/17	
Concept design	10 days	Mon 31/07/1	Fri 11/08/17	
Concept definition	9 days	Mon 21/08/1	Thu 31/08/17	
Detailed design	24 days	Mon 21/08/1	Thu 21/09/17	9
Engineering design	58 days	Mon 31/07/1	Wed 18/10/1	
Prototyping & testing	45 days	Thu 21/09/17	Wed 22/11/1	9;11
Homologation trials	65 days	Fri 22/09/17	Thu 21/12/17	9;11;12
Test product with users	79 days	Fri 01/09/17	Wed 20/12/17	
Process design	54 days	Fri 01/09/17	Wed 15/11/1	12
Production plan	58 days	Fri 01/09/17	Tue 21/11/17	
Supplier and material selection	34 days	Fri 01/09/17	Wed 18/10/17	
Tooling preparation	60 days	Fri 01/09/17	Thu 23/11/17	
Start of production	17 days	Fri 08/12/17	Sun 31/12/17	
Product launch	22 days	Mon 01/01/1	Tue 30/01/18	14

Figure 2.4: Real Gantt chart

The idea generation and the detailed design tasks remained critical, as it was in the original Gantt, but the protyping phase was the most difficult one. Especially the homologation trials task last 65 days respect to the original 50 days and the test product with users lasts 79 days instead of the original 61. In summary, the real Gantt chart showed longer task duration but distributed in a better way but, above all, testing and prototyping longer phase lead to a better product and avoid errors during production phase.
Moreover, the introduction of a modular project in the company project portfolio enables to parallelizing partly some activities, such as product design started before concept development is complete and process design is begun long before product design is finalized. In this way there exist a closer coordination between the different stages and minimizing the chance that R&D will design products that are difficult or costly to manufacturing.

Chapter 3

Product planning

Before starting with the first phase of NPD study, it is good to notice that how the project has been chosen and with which methods has been followed. Project Management background has been already treated in the previous chapter, while considerations regarding reorganization of the company after product development regards the core aim of the thesis and they will be explained after, in Chapter 7.
Product planning is the first NPD phase that every new product should face: it is, by definition from the Business Dictionary,

> the process of coming up with a business idea for a manufactured good, preparing the good for production and then introducing it to the market.

Product planning phase generally starts with the dual exploration of tacit or explicit market needs and of technological opportunities. The prevalence of either of the two determinants depends on the type of innovation (i.e., incremental or radical) the company wishes to pursue.
In our case market needs for GT-PAD were:

External input	Alpine The French society - part of Renault company - asked to develop a new racing seat for competingin A21 Cup with a GT4 car. Ferrari 458,Ferrari 488, Abarth 124 The three cars show in common a small cockpit and they are usually driven by high stature men.
Internal input	GT-300 replacement Sabelt company decides to replace the GT-300 seat with a new racing seat compliant with the new homologation requirements.

Table 3.1: GT-PAD market needs.

Thus, because of the new racing seat was born as a substitute product, the type of innovation pursued is incremental. In this context, the development process is market-pull, as the company wants to sell in an already existing market. The principle used for defining the market is the product similarity one: starting with the products already present in Sabelt's range, the development of the new seat is based essentially on the gained experience added with new processes and new manufacturing tools. The focus on product planning phase is on customer satisfaction due to the augmented importance on product quality and on reaching the closest product a customer would buy.

3.1 Understanding the market

For providing a clear market understanding, more than a Kano model or a QFD analysis, a Factor Analysis was applied. Factor Analysis started with a survey provided online and on different customers reached during Professional Motorsport World Expo 2017 in Cologne in November and at PRI fair in Indianapolis (USA) in December.
The survey's answers showed that:

- The majority of respondents were male (56,3%) with an age between 16 and 65;
- They were professional workers, owners of a car that drive daily, especially for work or study (83,9%);
- The majority of interviewees wouldn't like to change something in their car and, if exists the possibility, the 22,6% would change engine components, followed, jointly winners, by who want to change electronic parts or something related to seats & body in their car (16,1%);
- The statistical sample of respondents includes motorsport passioned (who watches F1 on TV for example) for 51,6%, followed by people with practical experience in a team (38,7%), then who goes karting/rallying (6,5%), with only 3,2% far from the racing world;

The questionnaire then focused on major seat characteristics, asking to ranking from 1 to 5 some peculiarity such as ergonomy or personalization features.
The answers are shown in the table below:

Question number	Question	Ranking 1-5
1	A seat that is comfortable	4
2	A seat that is easy to mount to the body of the car	3
3	A seat that fits well with your body	5
4	A seat with head and shoulder protections	5
5	A seat where security harnesses fit well	5
6	A seat that can be customized in colours and cushions	4
7	A seat with breathable foam	3
8	A seat that ensures an high safety factor	5
9	A seat made by innovative materials	4
10	A seat designed following customization requests	4
11	A seat with structural reinforcement	4
12	A seat with anti-slip fabric	3
13	A seat with an high quality of the finish	4
14	A seat that is not bulky	4
15	A seat that can be easily removed and washed	4

Table 3.2: Survey's seat characteristics answers

These 15 questions correspond, for Factor Analysis, to tertiary needs, i.e. the most elementary ones that can be elicited by interacting with customers. It should be noticed that tertiary needs are not technical features but vague requirements of customers.
Secondary needs are a mere aggregation of tertiary ones: in our case from 15 tertiary needs we obtained 9 secondary needs, as described in the table below:

Question number	Question	Ranking average
1	A seat that is comfortable	4
2	A seat with easy maintenance procedures	3,5
3	A seat that can be customized	4,3
4	A seat where security harnesses fit well	5
5	A seat with high technical characteristics	3,75
6	A seat that ensures an high safety factor	5
7	A seat made by innovative materials	4
8	A seat with an high quality of the finish	4
9	A seat that is not bulky	4

Table 3.3: Secondary needs

The tertiary needs 2 and 15 have been unified, forming secondary need number 2: a seat with easy maintenance procedures; needs 3, 6 and 10 creates secondary need number 3 regarding seat customization; needs 4, 7,11 and 12 realize the fifth secondary need about high quality of technical characteristics. In the third column average value of the ranking has been reported. Moreover, in the survey also the hypotetic price for a racing seat has been asked. The table below shows the supposed price with the relative answers percentage:

Price	Answers percentage
100€	13,6%
150€	8,2%
200€	14,1%
300€	18,5%
400€	17,6%
500€	20,3%
1000€	3,4%
2000€	4,3%

Table 3.4: Customer proposed price

Obtaining as an average weighted selling price of 401,5 €.

The last part of Factor Analysis focused on searching primary needs applying statistic principles, using STATA software as aiding tool. The first part is to name every secondary need with a representative word. In our case are: Comfortability, Maintenance, Customization, Safety Harnesses, Technicality, Safety, Innovative materials, Quality, Bulkiness. Factor Analysis (FA) and Principal Component Analysis (PCA) extract from a set of p variables a reduced set of m components or factors that accounts for most of the variance in the p variables. In other words, the aim is to reduce a set of p variables to a set of m underlying superordinate dimensions. The 9 secondary needs, that now are our variables, were inserted in STATA software and, after 2 iterations, Varimax and Rotated Matrix functions showed interesting foundings.
Varimax function shows the explained variance of the sample: in our case was 63,03% selecting three principal final components, 46,82% choosing only two; the decision of finding 3 primary needs was effectively correct. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy is a measure of the proportion of variance among variables that might be common variance. Factor Analysis, using KMO MSA as index, shows if the sample is adequate or not. In our case KMO MSA was 0.665, positioning in the mediocre, but still acceptable, range.
The Rotated Component Matrix shows finally which secondary needs can be aggregated into three different extraction components, as it is shown in the figure below:

Matrice dei coefficienti di punteggio dei componenti

	Componente		
	1	2	3
COMFORTABILITY	,453	-,287	,162
MAINTENANCE	,476	-,044	-,134
CUSTOMIZATION	-,074	,331	-,023
SAFETY HARNESSES	,322	,222	,104
TECHNICALITY	-,009	,433	,007
SAFETY	-,082	-,069	,574
INNOVATIVE MATERIALS	,180	,237	,078
QUALITY	-,124	,515	-,033
BULKINESS	,112	,213	,202

Metodo estrazione: analisi componenti principali.
Metodo rotazione: Varimax con normalizzazione di Kaiser.
Punteggi per componente.

Figure 3.1: Primary needs in STATA

From the table we obtained as final result three primary needs. The first one collects Comfortability and Maintenance and could be described as 'A seat that is comfortable and easy to maintain', the second primary need is about customization and could be expressed by 'A seat with high technological innovation rate and many customization possibility', the last primary need is about safety and can be easily represented by 'A seat that is safe' sentence.

So, as a general intent, after having identified primary market needs, the objective of the new development project have been identified. The new development project starts maximing the space inside the narrower cockpit for a gentlemen driver, i.e. usually a man of a big size with usually has a racing car for entertainment, having seats that are comfortable and easy to maintain, safe and that can be customized.
From the customization perspective, the seat born as a modular seat: the shell is conceived individually and then different cushions - called pads - can be litterally attached with velcro to the shell, forming the final seat.
The modularity of the product is advantageous because of:

- Pads can be easily changed: in a manufacturing perspective, the saddling of the seat is the most difficult part. Using pads the saddling operation becomes easier;
- There is a better adaptability to the physical physiognomy of the driver, allowing customization in different cushions sizes;
- Different cushions of different sizes can coexist together, shaping perfectly driver's body.
- High level of customization of shape and colors.

3.2 Product positioning

Product positioning means describing the new product with respect to the way it satisfies primary needs, eventually in relation to competing products, defining its target customers ([34]). In our case, the GT-PAD racing seat is horizontally differentiated respect to the range seat available in Sabelt catalogue.
The range of racing seat available in fact is:

- **GT-910** Full carbon seat with aestethic Textreme finishing;
- **GT-635** Carbon fibre seat designed for Circuit and Rally;
- **GT-625** Carbon fibre seat developed for the specific use on the track;
- **GT-621** Shell made with high resistance carbon material, with a final weight (including impact absorber, foams, fixing plates and cover) of less than 10 kg, which puts this model at the top of the range;
- **Titan Carbon** Autoclave carbon fibre shell with anti-slip fabric on shoulder and innovative breathable fabric on backrest and bottom;
- **Titan** Gel coat shell with a rounded design which underline the lightness of the racing seat;
- **Taurus** Gel coat racing seat with well defined head protection and a high density foam;
- **GT-3** Fibre-glass shell with an innovative and lightweight lamination tecnique;
- **Racer Duo** Tubular steel frame structure with an excellent lateral support.

The GT-PAD enters in the range of Sabelt racing seat in the 2018 catalogue as the first modular seat developed internally to the company, exploiting the knowledge about GT-3 fibreglass shell (economies of scope objective, also sharing platforms and flexible manufacturing systems that can be shared in common) and adapting to a new market segment. The GT-PAD in fact is conceived for satisfy medium-high range of customer, especially customers with an higher reservation price for that product, which leads potentially to higher margins.
Product positioning affects also product pricing: in the case of GT-PAD in fact we said that the product is horizontally differentiated. This allows Sabelt company to get close to the maximum utility of a given segment: as a consequence, an higher price can be asked. The horizontal differentiation leads also to partitioning aggregate demand in many segments, leading consequently to lower volumes in each segment since the company has to give up central offerings and economies of scale.

Three main elements are important in an horizontally differentiated product pricing:

- **Size of the market segment:** in the GT-PAD case at least 2 big clients (Ferrari and Renault Alpine) plus more other minor racing customers create a wide market segment;
- **Customer willingness to pay:** GT-PAD will be sold to gentleman driver, i.e. people with an high willingness to pay. The motorsport sector in fact is an expensive world that requires an high amount of investments;
- **Sensitivity of demand:** as in the case of customer of willingness to pay, sensitivity of demand is low. Customers are affected in a low measure about price changing.

When the three elements are at a high level, the price of the product can be considered in a medium-high range of price.
Another part of product planning is demand forecast for the new product that has to be sold. The demand is generally found using the formula:

$$D_j = D \times S_j \times AW_j \times AV_j \tag{3.1}$$

where

- Dj is demand for product j, in our case the demand for GT-PAD seat;
- D is a forecast of overall demand in the market segment;
- Sj is the market share that product j could potentially achieve, based on its features, and is therefore directly connected to design decisions;
- AWj (awareness) is the fraction of target customers who can be expected to know of the product's existence, which is related to marketing actions that the firm will undertake to this purpose;
- AVj (availability) is the fraction of target customers who will be able to purchase the product, based on the distribution strategy followed by the firm.

The GT-PAD is a mature product, i.e. a product with a stationary market demand D and so overall demand in the market segment can be studied using historic time series. Forecasting methods based on time series try to extrapolate the future behaviour of demand starting from the analysis of its past trend: they assume that the demand in the past could be a clear forecast for the demand in the future.
The forecasting method used in this analysis is the simple exponential smoothing forecast method, where past observations are weighted in a decreasing way over time. The general formula for demand formulation is:

$$F_{t,h} = \alpha Y_t + (1 - \alpha) F_{t-1,h} \tag{3.2}$$

where F states for forecast, t is the time and h is the horizon period. α is a parameter whose value is between 0 and 1 and it's the most difficult part of the formula, because the choice of α influences the reactivity of the model itself. If α is equal to 1, the model becomes a simple moving average demand forecasting model, attributing to every past

observation same weighted importance.
Another formulation of the the simple exponential smoothing forecast method is:

$$F_{t,h} = \alpha Y_t + (1-\alpha)F_{t-1,h} = F_{t-1,h} + \alpha(Y_t - F_{t-1,h}) \tag{3.3}$$

that is the formulation of major relevance for us: the new forecasting is equal to the forecasting done in the time-step before plus an other term that shows the error done in t-1 in forecasting the demand Y_t, only affected by a parameter α.
α has been chosen with a small value, i.e. $\alpha = 0.1$, because in this way the model reacts immediately at demand changes and it is able to filter unpredicted changes, not given to them an high weight.
Our sample is composed by 15 statistical observations with a time period of 3 month per 5 years (from 2013 to 2017 included). For initializing the forecasting method and attributing a value to $F_{t-I,h}$, where I is the total time horizon considered in periods, the first 4 l periods will be used for setting it, trough the formula

$$F_{t-I,h} = \sum_{i=t-I+1}^{t-I+l} \frac{Y_i}{l} \tag{3.4}$$

Here below the table shows, for the major product lines of the most important competitor of Sabelt,the seats sold during the 5 years horizon with their relative sales volumes:

	I trim. 2013	II trim. 2013	III trim. 2013	IV trim. 2013	I trim. 2014	II trim. 2014	III trim. 2014	IV trim. 2014	I trim. 2015	II trim. 2015
Sabelt SpA	654	498	385	426	876	632	620	558	780	545
Sparco SpA	1526	1002	996	1100	1742	995	964	870	1662	1010
OMP Racing	889	615	545	447	664	420	536	746	502	660
Alpinestars	354	221	415	289	537	365	624	452	488	420
Total	**3423**	**2336**	**2341**	**2262**	**3819**	**2412**	**2744**	**2626**	**3432**	**2635**

	III trim. 2015	IV trim. 2015	I trim. 2016	II trim. 2016	III trim. 2016	IV trim. 2016	I trim. 2017	II trim. 2017	III trim. 2017	IV trim. 2017
Sabelt SpA	180	600	750	550	535	420	810	630	505	450
Sparco SpA	856	742	1245	990	1100	840	1250	915	1000	960
OMP Racing	450	550	862	395	455	360	640	405	270	420
Alpinestars	650	548	650	525	365	580	740	495	780	560
Total	**2136**	**2440**	**3507**	**2460**	**2455**	**2200**	**3440**	**2445**	**2555**	**2390**

Figure 3.2: Sales volumes

founding that the forecasting for the market for the year 2018 (so, having an horizon periods equal h=4), with t=20 (using 20 we are doing the forecasting being at the last trimester of 2017), I=19 trimesters, l=4, is

$$F_{1,4} = \sum_{i=2}^{5} \frac{Y_i}{4} = \frac{10758}{4} = 2689{,}5 \tag{3.5}$$

that, because seats are sold per units, will be rounded up to 2690. So, finally, the forecasting for market demand, for the next 4 time periods, i.e. one entire 2018 year, setting $\alpha = 0{,}1$, is:

$$F_{20,4} = 0{,}1 \times 2390 + (1-0{,}1) \times 2689{,}5 = 2689{,}5 + 0{,}1(2390 - 2689{,}5) = 2659{,}5 \tag{3.6}$$

rounded down to 2660.
The graph below shows the sales volumes, assuming that in our case the volumes satisfy completely the demand, so it is assumed that volumes sold are equal to the demand, and the forecasting method estimation:

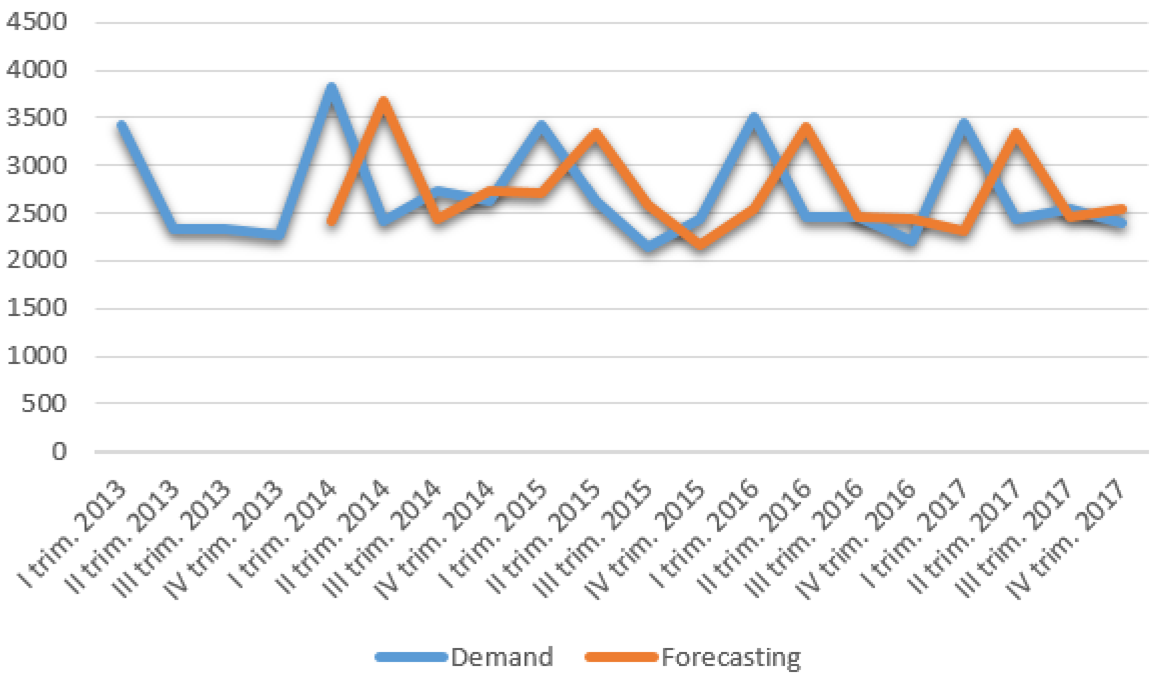


Figure 3.3: Simple exponential forecast

As already said, the first 4 periods have been used for initialized the method so they don't have a forecasting estimation. The demand for seat could be defined constant over the years, but, as it is shown in the graph,in the first semester of every year the demand has a notable peak in every year analysed. The forecasting method however well follows the demand and it is also able to predict the peak and redistribute the demand all over the following periods.

Regarding S_j, i.e. the market share of our product, the Kotler's theorem has been applied. The theorem relates market share of each product to a measure of "attractiveness" A_i of all competing goods. The atractiveness of a product is directly related to its marketing effort because, hopefully, the greater the marketing effort of a firm the greater should be its market share. In mathematics, this can be translated with the formula:

$$S_j = \frac{A_j}{\sum_i A_i} \tag{3.7}$$

stating that the market share of firm i (in our case Sabelt SpA) is equal to thefirm's marketing effort divided by the sum of marketing effort for all competitors in the industry. Obviously attractiveness of each product is always non-negative and a product with zero attractiveness has zero market share. Attractiveness A_j can also be related to an effectiveness parameter α, because even if two firms expend the same amount of marketing effort they may not have the same market share. In this case, the formula becomes:

$$S_j = \frac{\alpha_j A_j}{\sum_{i=1}^{m} \alpha_i A_i} \tag{3.8}$$

For determining A_j three different attractiveness models can be used:

- **Linear model** $A_j = \alpha_j + \sum_k \beta_k\, X_{jk} + e_j$ where α_j is a parameter for the influence of the brand, β_k is a parameter that shows the influence of technical characteristic on the final product based on past sales, X_{jk} is the set of technical characteristics and e_j is an error term;

- **Multinomial Logit model (MNL)** $A_j = e^{\alpha_j + \sum_k \beta_k X_{jk} + e_j}$
- **Multinomial Competitive Interaction (MCI)** $A_j = e^{\alpha_j} \prod_k X_{jk}^{\beta_k} e_j$

The MNL and MCI are nonlinear models, so they become of difficult computational effort. For this reason in this work linear model has been used.
For determining α, β and X some benchmarking has been done among the main competitor of Sabelt inside the italian territory:Sparco S.p.A, OMP Racing and Alpinestars. Here below the table represents the four firms related with some investments useful in determining the success of a new product: the price, the advertising and the R&D expenditures (these specifications determine the X parameter related to technical characteristics of the finale product). β factor is determined by the influence that these cost item have on final product: briefly, every expense is compared with the sum of others. α is given by the analysis done on the introduction of the e-commerce for all the companies: OMP Racing and Sparco have benefited most from it and they show a greater α respect to the other two companies (the analysis has been done analysing the net incomes found on internet and how the net income itself grows after e-commerce introduction).

Firm	α	**Avg Price**	**Advertising**	**R&D**	**Market Share**
Alpinestars	0.7	480€	50 000€	35 000€	17.91%
OMP Racing	1.3	390€	45 000€	80 000€	21.25%
Sabelt S.p.A.	0.9	405€	70 000€	80 000€	28.72%
Sparco S.p.A	1.5	355€	80 000€	150 000€	32.12%

Table 3.5: Kotler's Theorem numerical application

with parameters β_{price} = -1.5, $\beta_{advertising}$ = 0.8 and $\beta_{R\&D}$ = 0.6.
Obviously β influence related to price is negative because greater is the price less the customer will buy the product.
In this way A_j is obtained for the four firms in this way (using the linear model):

$$A_{Alpinestars} = 0.7 + (-1.5)(480) + (0.8)(50000) + (0.6)(35000) = 60930.7 \quad (3.9)$$
$$A_{OMPRacing} = 1.3 + (-1.5)(390) + (0.8)(45000) + (0.6)(80000) = 83416.3 \quad (3.10)$$
$$A_{SabeltS.p.A} = 0.9 + (-1.5)(405) + (0.8)(70000) + (0.6)(80000) = 103393.4 \quad (3.11)$$
$$A_{SparcoS.p.A} = 1.5 + (-1.5)(355) + (0.8)(80000) + (0.6)(150000) = 153469 \quad (3.12)$$

obtaining finally the relative market share for each company:

$$S_{Alpinestars} = \frac{60930.7}{83416.3 + 103393.4 + 153469} = 17.91\% \quad (3.13)$$
$$S_{OMPRacing} = \frac{83416.3}{60930.7 + 103393.4 + 153469} = 21.25\% \quad (3.14)$$
$$S_{SabeltSpA} = \frac{103393.4}{60930.7 + 83416.3 + 153469} = 28.72\% \quad (3.15)$$
$$S_{SparcoSpA} = \frac{153469}{60930.7 + 83416.3 + 103393.4} = 32.12\% \quad (3.16)$$

The last two parameters of the formula are the awareness AW_j, which value is similar to A_j because is influenced by marketing actions, so in our case we will assume a parameter $AW_{Sabelt} = 0.28$ and availability that we can assume have a value $AV_j = 0.8$ because Sabelt SpA is a well-known company that act in the seat-manufacturing market as an incumbent (in fact it is in the market since 1972).
Finally, the demand D_j for our new seat can be calculated:

$$D_{GT-PAD} = 2660 \times 0.2878 \times 0.28 \times 0.8 = 171.45$$

rounded up to 172.

3.3 Product specification

It is now essential to move on from the user needs gathered during market research into a more detailed compilation of user requirements and then — given a product concept — to product design specifications (or, in short, product specifications). While user needs are typically expressed in a qualitative way, requirements are defined at a definite and measurable level, without, however, telling how they will be technically fulfilled. A product specification can instead be defined as a list of product features, functions and parameters whose values are set so to comply with user requirements, defined according to norms or standards. It should be noted that two elements are very important from a conceptual point of view and must be highlighted. First of all, the transitions from need to requirement and from requirement to specification are not simple translations, but are the outcome of design decisions, since they could lead to many different alternatives. Secondly, the step from user requirements to product specifications assumes that an underlying product concept has already been defined. In our case, because design activities deal with incremental innovations,that will not substantially change the product concept, the company will seamlessly move from the definition of user requirements to product specifications. In the case of radical innovations, product specification and concept generation will instead overlap and possibly lead to iterations.
The product specification phase is characterized by a number of challenges:

- **The interfunctional nature of the activities** because user requirements definition and product specification occur at the interface between the marketing and technical departments of the firm, carried out among professionals who came from different cultural background and with different objectives;
- **The quantity of information** is huge, because product specifications lists can be very long and complex;
- **The uncertainty of information** because detailed design has not been carried out yet or maybe product specifications may either be technically unfeasible or resulting into a product with low attractiveness and disappointing returns.

For these reasons, a correct product specification definition can be considered to rely on appropriate information sources and on the use of a sound methodology an moreover, it should cover all the life-cycle phases of the product. Sources of information can come from the industry (competitor analysis for example, already exploited during benchmarking) or from official sources (norms and standards) but the most relevant source is coming from user, defining the so called *user-centered design specifications*. User-centered design is based on observing and detailing user interactions with the product. This leads to defining specifications with respect to interaction modalities and the user interface of the product, defining:

- **Personas**, i.e. fictional characters that embody the needs and traits of specific target users: in the GT-PAD case personas are identified as a gentlemen driver, with a strong motorsport passion, who consider races as occasional funny moments full of adrenaline;
- **Scenarios** that represent fictional narratives of the context in which the persona interacts with the product: in our case scenario is represented by moments spent

on the track or during car set preparation, inside in a garage or done by a highly specialized mechanic;

- **Use cases** that show step-by-step description of the interactions between the user and the product. In GT-PAD case the use case is given by the interaction between the mechanic and the seat during car setting or between the driver and the seat during races.

User requirements and product specifications can be defined following a variety of methodologies. In GT-PAD project Quality Function Deployment QFD has been used: in fact, according to its principles, QFD should be used to support the entire development process, from the initial phase of requirements definition and product specification, all the way to the design of manufacturing processes and quality assurance systems. The House of Quality shown below has as customer requirements the secondary needs found during market research and columns express technical requirements. Benchmarking has been carried among two competitors already illustrated before plus a new one (MOMO) and the relative weights have been decided by the two technical guys who completely followed the project. The competing seats chosen as competitors for the benchmarking are shown in the figure 5.5.

Technical features definition have been carried out on the vertical part of the House of Quality under the leadership of technical designer, together with technical features weighting. The strength of the relationships between each customer requirement, on columns, and each technical feature, on rows, is expressed by the degree with which customer requirement i is affected by technical feature j. In our analysis the degree's value is equal to 1 (very weak relationship) represented by a red rhombus, is 3 for a weak relationship, shown by a yellow triangle while the blue circle represents the strong relationship, with value equal to 9, between customer requirements and technical characteristics. At the end of QFD analysis, technical relative importance computation and relative weight computation for customer requirements identified, as more important are:

- For customer requirements there's the need to implement 'A seat that can be customized', with 47,9% of importance, followed by 'A seat made by innovative materials' with 13,3% of importance;

- Regarding technical characteristics, 'Comfortability' has 11,7% of relevance, followed by 11,2% of 'Safety' importance.

Technical characteristics founded are not so surprising, because they combine the basic and essential characteristics of a seat, without which the seat would have no way of existing; on the other hand, customer requirements are surprising, because customization feature has never been introduced so much in detail in a racing seat design.
For this reason GT-PAD project focused on customization matter for the first time inside Sabelt SpA history, always leading the principle of safety and comfortability always alive. Customization and modularity issue so have been introduced during the development of this seat.

(a) *Daytona MOMO*

(b) *HTE-One OMP Racing*

(c) *Pro 2000 Sparco SpA*

(d) *GT-PAD Sabelt SpA*

Figure 3.4: Modular seats benchmarking analysis

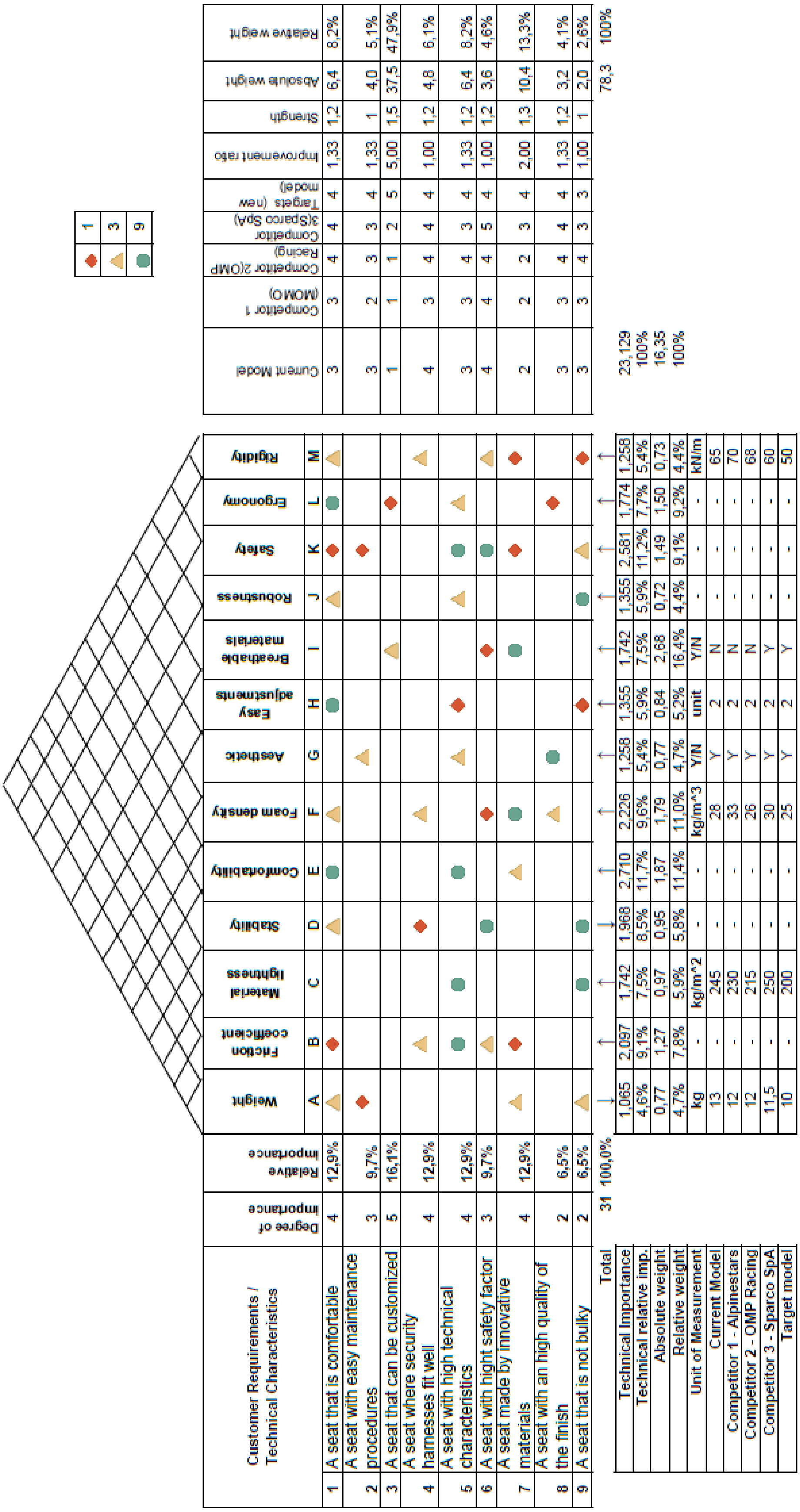


Figure 3.5: QFD analysis

3.4 Product costing

Cost estimation is a key element of the product development process and it obviously impacts the firm's performance: this activity in fact can lead to mistakes that have strategic relevance, since an underestimation of costs leads to financial losses, while an overestimation will lead to a high price and the loss of market opportunities. Target Costing approach has been used in this thesis work and it considers cost as an independent variable of the product development process. In target cost approach product requirements are immediately matched with a target price, which is estimated as the price that customers would be willing to pay for a product with these same features; in case of incremental innovations target pricing is usually defined by comparing the new and improved product with the existing one and then estimating customers'willingness-to-pay for these improvements. Given the target price, the firm applies a desired contribution margin, thus deriving the target cost, which then becomes the cost of the product specifications. There are several methods for product cost estimation: qualitative methods (both intuitive and analogical) or quantitative methods (parametric or analytical). More in details, the method used in this thesis is the Activity-Based Cost ABC whose helps decision-making procedures for product modularity. The basic rationale for introducing a modular product is to obtain a cost reduction, diminishing time to market but unchanging product variety.
Activity-Based Cost is basically a two-stage procedure that assignins indirect costs to products and services which involves finding cost of each activity involved in the production process and assigning costs to each product based on its consumption of each activity. Moreover, it is a methodology for more precisely allocating overhead to those items that actually use it. The first part of ABC is the identification of activities involved in the production process and in our case they are listed below:

- Designing;
- Components supply;
- Saddling;
- Pad assembling;
- Testing;
- Quality inspection;
- Packaging;
- Shipping.

while the table below shows the total activity cost for a production of a batch of 50 GT-PAD, 50 TITAN and 50 GT3 and how indirect cost are allocated among three different product line that produces fibreglass seat but with different characteristics. The relative cost drivers for every founded activity are listed below:

Activity	**A[€]**	**Cost Driver**	**TITAN**	**GT3**	**GT-PAD**	**Total**
Designing	9000	Designer hours	100	60	85	245
Components production	3600	Machine hours	13	10	18	41
Saddling	3000	Labor hours	8	8	6	22
Assembling	800	Labor hours	1	2	1	4
Testing	4500	Testing hours	150	120	130	400
Quality inspection	1500	Man hours	2	2.5	3	7.5
Packaging	900	Units	1	1	1	3
Shipping	1500	Units	1	1	1	3

Table 3.6: Resource cost drivers

A is the total cost of the activity for the three seat while after every seat has assigned its cost drivers value.
Then, the cost per unit for every cost driver has been found:

Activity	**Cost driver unit cost [€]**
Designing	9000/245 = 37
Components production	3600/41 = 88
Saddling	3000/22 = 136
Assembling	800/4 = 200
Testing	4500/400 = 11.25
Quality inspection	1500/7.5 = 200
Packaging	900/3 = 300
Shipping	1500/3 = 500

Table 3.7: Cost drivers unit cost

and, finally, the charge of cost on every product line could be done:

Cost driver cost	**TITAN**	**GT3**	**GT-PAD**	**Total TITAN**	**Total GT3**	**Total GT-PAD**	**Total**
37	100	60	85	6100	3660	3145	12905
88	13	10	18	1144	880	1584	3608
136	8	8	6	1088	1088	816	2992
200	1	2	1	200	400	200	800
11.25	150	120	130	1687.5	1350	1462.5	4500
200	2	2.5	3	400	500	600	1500
300	1	1	1	300	300	300	900
500	1	1	1	500	500	500	1500

Table 3.8: Allocation cost among 3 different product lines

and summing to indirect cost the direct one, the total cost for every product line is obtained, considering as direct cost COGS and man hours spent in doing a batch of seats:

Costs	**TITAN**	**GT3**	**GT-PAD**
Direct costs	2850	2020	3650
Indirect costs	11419.5	8678	8607.5
Total costs	14269.5	10698	12257.5

Table 3.9: Total cost for fibreglass product lines

obtaining finally the total cost of every product line and dividing it for the 50 units of the batch we obtained respectively a unit cost of €285,39 for TITAN, €213,96 for GT3 and €245,15 for GT-PAD.

Chapter 4

Design phase

Many design researchers believe in the aphorism ‘necessity is the mother of invention’: a need acts as the initial motivational force that provides the basis for starting design work. Willem [57] explicitly expressed that the universal feature of design is simply the intentional devising of a plan or prototype for something new. The need or intention forms the first basic elements of all designs, i.e. the problem to be solved; as a consequence many designers believe that the output or product of a design is a symbolic representation of an artefact for implementation.
A basic feature of design that almost all design researchers accept implicitly or explicitly is the transformational nature of design. They noted that need acts as a seed that design transforms into a form that is eventually used to guide the implementation of an artefact, plan or process. Design is so as a creative activity – it involves bringing in something new and useful that has not existed previously. However, creativity remains an elusive subject of design researches and still beyond science’s firm grasp. The precise manner in which new ideas are generated still cannot be identified. There exist two styles of idea generation: abstraction and elaboration. Abstraction is used to make generalisations while elaboration attempts to develop into great detail the specifics of a design. In GT-PAD case the part of elaboration has been taken in account with so much weight respect to abstraction: developing seats is basically the main business of Sabelt SpA, so what is missing is the step over towards the modular product design.
Also constraints are of relative importance during design phase and they are often discovered during the design work itself. Such constraints apply both to the designed artefacts and to the processes and participants involved in the design activity. Several problem characteristics occurred during phase and, because of the highly-structured complex problem that the design represent, the most frequent problems are:

- No definitive formulation of the problem: when a design problem is initially set, the goals are usually vague and many constraints and criteria are unknown: in GT-PAD case the initial idea of a modular product wasn’t even thought before;

- No definitive solution to the problem: essentially, this implies that there is a lack of any criteria that can be used as a ‘stopping rule’ to establish when the solution to a problem has been found good. In case of GT-PAD, the final design validation occurs after prototyping and testing phase, where the seat has been recognized valuable from customers;

The constraints of GT-PAD were imposed by FIA regulations in order to get the homologation number: be compliant with the rules was one of the major problem for designers.
The main result of the design activity must be presented in the form of a description of the designed product. In GT-PAD case, the complete drawing of the seat has been done and it includes measures, such as length and depth of the seat, fixing points and tolerances. The image below shows the final GT-PAD technical drawing, that will be illustrated also during the chapter about production(n° 6).

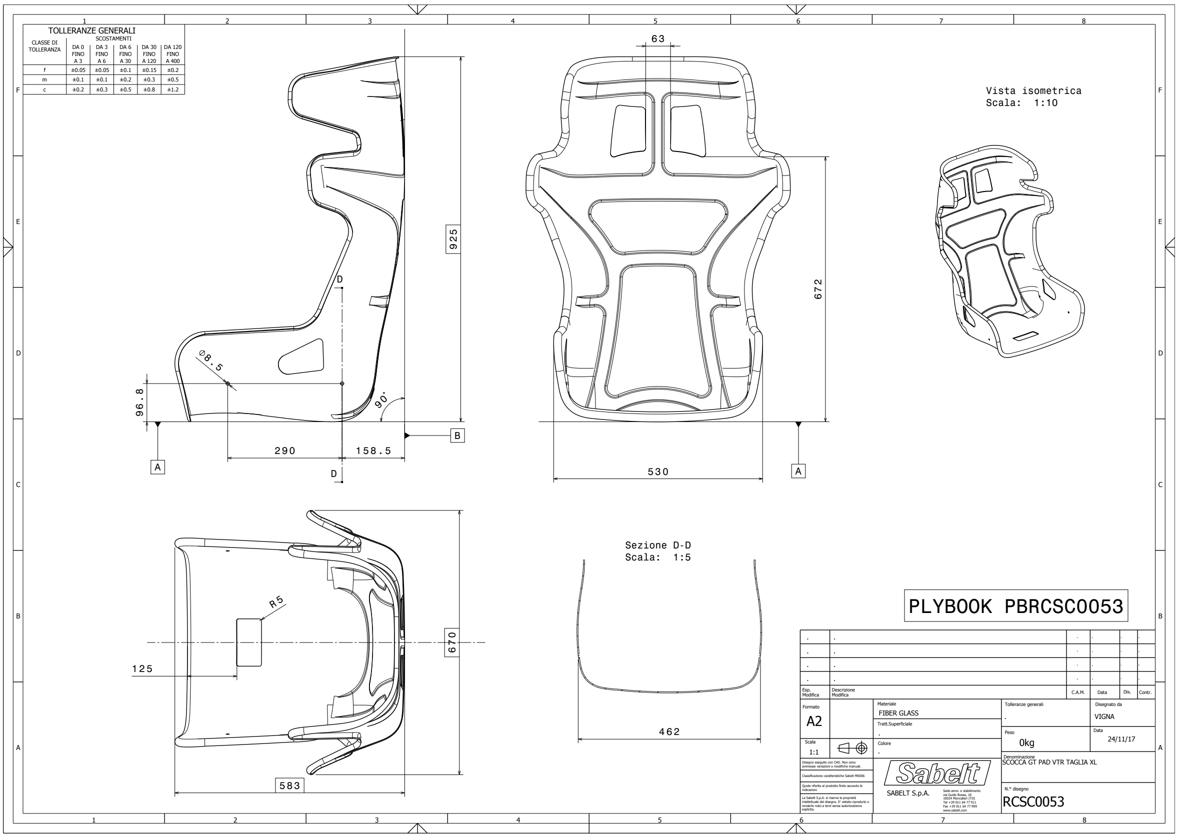


Figure 4.1: GT-PAD technical drawing

This technical drawing explains also how the shell, made of fibreglass plies, has to be made: the collection of plies manufacturing method is called plybook.

4.1 Concept design

Before starting with concept generation, several requirements for design should be set. First of all, a list of sources from which one can derive information and inspiration on current car seats has been done, founding a good source of knowledge in ergonomy studios, regulators, industrial design studios, new concept cars that try to anticipate the future from the incumbents' point of view, University and Research Centers, high-tech solution suppliers and car producers itself. Moreover, a preliminary list of the main needs and requirements that characterize a car seat has been done, don't limiting only to consumer-specific ones, as they are already been defined during product planning, but trying considering requirements that emerge from other sources along the product lifecycle, such as car makers or regulators. The main four phases of the lifecycle of a car seat have been analysed: they are material production phase, component manufacturing process,use phase and disposal. The image 4.3 shows current stakeholders needs and their related unit of measures.
Before doing a deeper concept design explanation, the thesis work focuses on the usability of the car seat, defining a set of personas, possible scenarios of user-product interaction and use cases that could be explored. Personas could be identified as customer segments, i.e. fictional characters with a name and a set of demographic and motivational attributes. In order to make the most complete possible description of the personas the table below shows different criteria relevant for customer segmentation. Choosing and combining an element per each set of criteria generates a segment, so the set of personas is given by all the plausible (not all combinations are possible) combination of elements (generally one per criteria, also 2 or 3 if it makes sense).

	sex [M/F]	age [years]	net income [€/month]	number of family members [num]	hours spent driving in usual day [hours/day]	hours spent being transported in usual day [hours/day]	Km made in car in an usual day [km]	occupied seat [defined scale] (allowed multiple choices)	mind-set [defined scale] (allowed multiple choices)	
START	M	0 - 18	0	1	0	0	0	front driver	lux-oriented	END
			1 - 500	2	0 - 0.5	0 - 0.5	1-50			
		18 - 25	500 - 1000	3	0.5 - 1	0.5 - 1	50-100	front side driver	performances-oriented	
		25 - 35	1000 - 2000	4	1 - 2	1 - 2	100-200		rationality-oriented	
	F		2000 - 4000	5	2 - 3	2 - 3	200-300	rear		
		35 - 60	4000 - 10000	6	3 - 4	3 - 4	300-400		comfort-oriented	
		60+	10000+	7	4 - 6	4 - 6	400-600	trunk seats	tech/innovation-oriented	
				7+	6+	6+	600+			

Figure 4.2: Personas analysis

Mathematically speaking, it would be possible to list exactly 5734400 (=2*5*7*8*8*8*8*4*5) segments, but actually this number should be reduced because not all combinations possible makes sense: this number gives only the magnitude of the size of the segments. Obviously, this number is too high to be managed, changing the number of elements per criteria or grouping the result is possible to make it smaller and more reasonable, obtaining in the end one possible personas description: a male adult with an high income, in a nuclear family of 4 people, spending between 1 and 2 hours driving and making 100-200 km per day; he likes performances and luxury branding, but also innovative technologies.

	MATERIAL PRODUCTION PHASE			COMPONENT MANUFACTURING PROCESS		USE PHASE			DISPOSAL		
NEEDS	R&D centers	Material suppliers	Regulators	Car seat producers	Regulators	Drivers	Car makers	Regulators	Buyers	Regulators	REQUIREMENTS
Material resistent to the strength	X	X		X			X				Technical features of the material like: Elasticity.......... Manufacturability, quality, lightweight materials, durability, modularity, ergonomics
Material easy to work	X	X									
Material available nearby to avoid high transportation costs		X									Component availability
Material/production should be not expensive to realise		X					X				Production cost
Standards respected			X		X						Certifications
Materials environmentally friendly			X		X					X	Environmental impact
Low emissions during production phase			X		X					X	
Feeling relaxed						X					Comfort
vocal reguations of the seat						X					Intelligent personal assistance
a seat able to take over the the temperature of my body						X					Data measure
measure heartbeat, breathing rhythm of drivers						X					
Detect tension in the muscles to start a massage						X					
Detects the traveler's drowsiness or stress and then takes countermeasures to relieve those conditions						X					
Respect personal tastes - customization						X					customized comfort and style
Affordable						X	X				price
Substituitable it in case of damage						X	X				After sales services
Able to stop the car and to call emergengy number in case of necessity (incident or abnormal body conditions)						X					safety

Figure 4.3: Current seat requirements

Scenarios are possible situation in which the new product could be involved in. In this thesis work, the focus have been set on environmental variables that could affects in some way the interaction between user and product. The scenarios founded during concept selection are:

- Sudden illness during driving;
- Stay relaxed during a medium-long trip;
- Sit in a hot/cold seat;
- Someone else used the car before, the driver doesn't fit with the position of the seat;
- The driver suffer a pain in the back;
- The driver is not able to find a comfortable but safe seat;
- A very important business partner has to be picked up at the airport;
- Driver wants to use a fast car on racetrack;
- Employees are installing the seat into the car;
- Safety tester is testing the vehicle;
- Vehicle ended its life, subcomponents must be disassembled;

Every scenario listed could occur in different situations and with different personas. Finally, use case shows the interaction between personas (users) and the product in a given scenario. The use case for GT-PAD is illustrated in the image below: the high-income gentleman driver drives his car during track days or for improving the performance of his fast car, finding the most reliable and safe driver position ever.

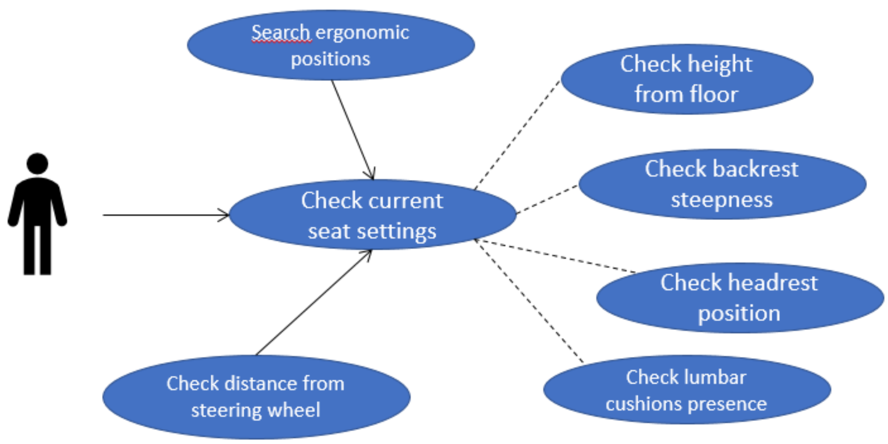


Figure 4.4: Use case diagram

Following Ulrich and Eppinger [56] it is possible to describe conceptual design as a top-down approach that follows 4 main phases: needs identification, problem definition, alternatives exploration and finally concept selection. This process shows convergent and divergent phases, that are, respectively, characterized by relatively unbridled creativity and rigorous analysis. The concept selection divergent and convergent methodology is illustrated in the figure below:

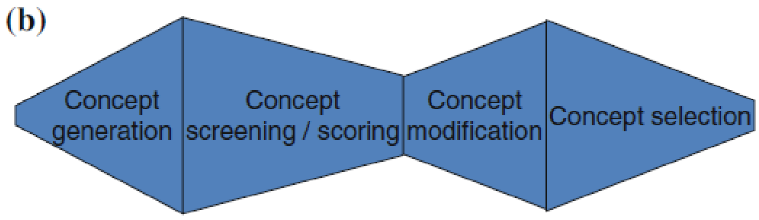


Figure 4.5: Conceptual design process

As we can see, concept generation show a divergent behaviour because many ideas should be evaluated and the prevailing one will pass through the second phase, concept screening, that leads than to concept modification, where again the process is divergent because several options are considered before reaching the final concept decision.
The first step in concept design is in functional analysis, explaining the required function of a product using a function tree. A function tree is based on the idea that a product can be described as a hierarchy of functions, starting from the root function that describes the core purpose of the product and progressively detailing each function by exploding it into sub-functions. The function tree of GT-PAD seat is shown in the figure 4.6. The main function of a seat is to keep the driver in the right position and, especially for racing seat, more functions could be derived: the racing seat should be stable, should give a good ergonomic position and mostly should be safe. From functional tree it is possible to derive the BoM of the product. The type of BoM chosen inside Sabelt SpA is a production BoM, i.e. a BoM that combines components by considering the way with which they will be assembled: in this way the information systems of the company are able to manage it and to guarantee its consistency. Other kind of BoM exist (functional, engineering, by technical discipline or by supplier) and they are all justifiable from an operational and logical perspective: in this case the production BoM is preferred because is the most used inside the company and a lot of knowledge has been already transferred on it from other products.
Observing the function tree and the BoM consequently, the link between lower-level functions and components can exhibit different cardinalities. In the case of a 1:1 association there is a clear identification of which component fulfils which function and vice versa. This functional separation between components leads to modular architectures that is properly the GT-PAD case. In fact every components is clearly associated to one function and changing it also the function can be instantaneously modified. The modular architecture of the product facilitates detailed design activities and the use of standard and off-the-shelf components. In our case, the materials used for the kit pad fall within the great world of foam, but choosing one foam of one supplier respect to another one, keeping the same density requirement, does not change anymore the functionality of the kit pad.

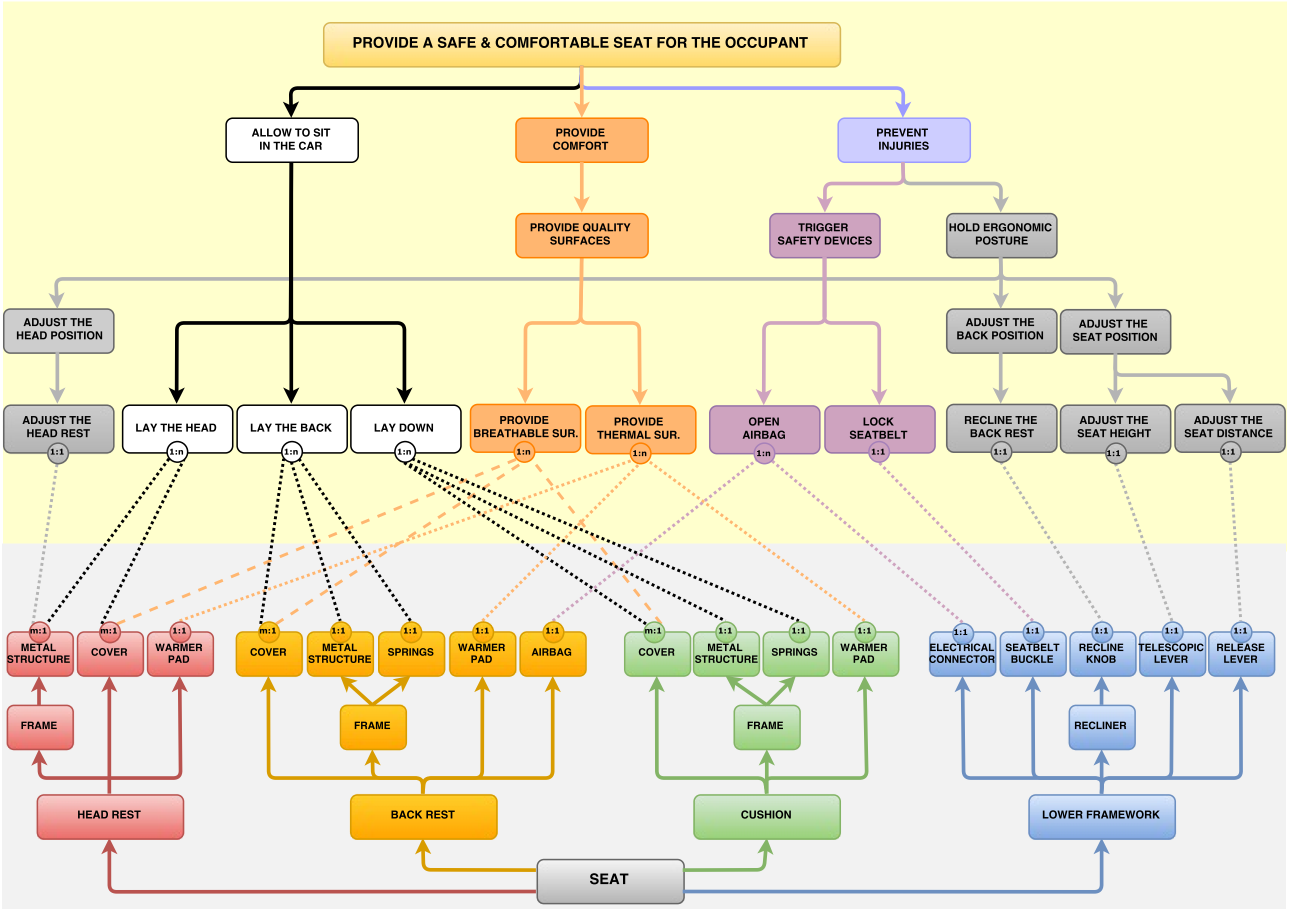


Figure 4.6: GT-PAD function tree

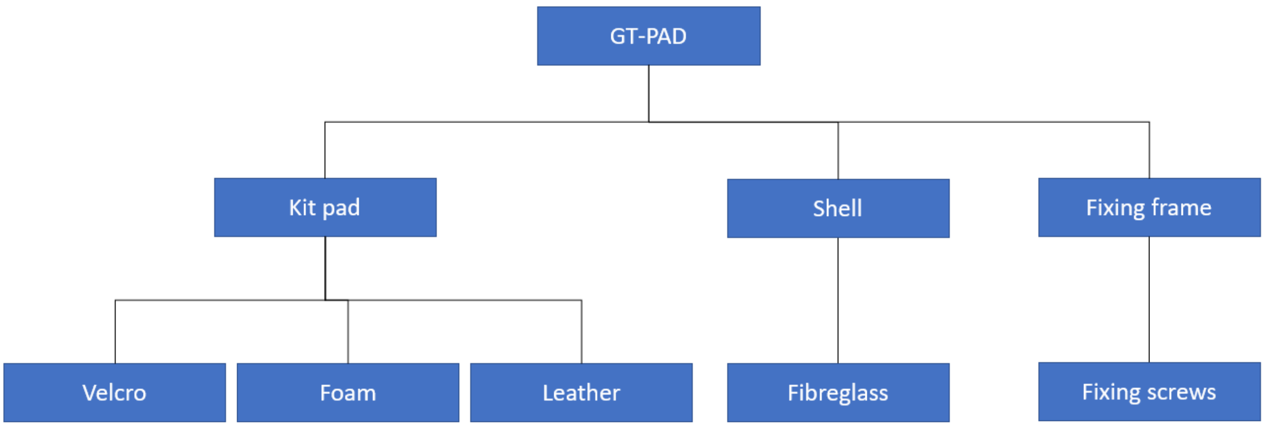


Figure 4.7: GT-PAD production BoM

Moreover, functional analysis can also be carried out with function diagrams such as Function Analysis System Technique (FAST) in which the product's functions are described by showing how a set of inputs is progressively transformed in a set of outputs by a network of functional elements.A FAST diagram for GT-PAD seat is shown in the figure below:

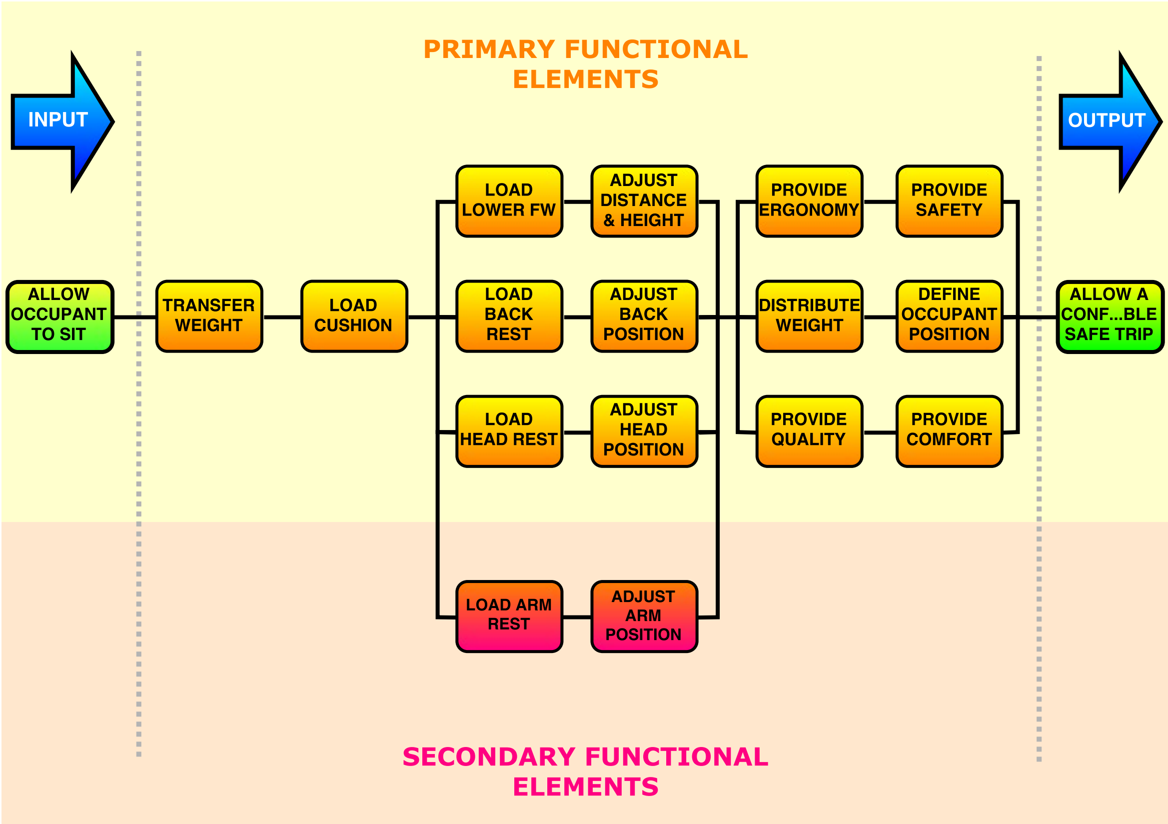


Figure 4.8: FAST diagram

In FAST analysis, primary (or core) functional elements are involved directly in the conversion flow of inputs into outputs, secondary (or auxiliary) functional elements instead are required only to enable the operation of primary functional elements.
Designer inside Sabelt SpA focused also on Gero's model during concept design: the Function-Behaviour-Structure ontology proposed by Gero in 1990 explains that the designer must first of all define the artifact's function (F-function), then choose a suitable working principle able to fulfill it (B-behaviour), and finally proceed to describe the artifact's form in detail (S-structure). In the case of GT-PAD seat, Function, Behaviour and Structure are:

- FUNCTION (F): The automotive seat is designed in order to provide a safe and comfortable seat to the vehicle's occupants. The dependence toward the domain is considerable and can be easily captured, since the common term "seat" is applicable to a multitude of daily-use objects, which are conceived to a variety of activities. In this domain, the automotive one, the functions of the seat are adapted to the environment from which it is surrounded. The need of ergonomy and safety during the trip are functions that are proper for this object in this domain and are considered primary, since removing them, the function will be not completely fulfilled.

- BEHAVIOUR (B): The behaviour of the automotive seat is conceived as the set of attributes that allow the object to perform its function described above. In order to provide a support to the occupant, the car seat transfer the weight of the individual to its own components in the right way to produce the conditions that allows him to attend the trip, preserving at the same time his health state and providing safety in case of danger due to both endogenous and exogenous factors. As the previous entity, the behaviour is strongly domain-dependent because of the seat acts in different ways depending on the environmental conditions that affect the occupant as time goes by.

- STRUCTURE (S): The structure of an automotive seat is conceived to connect each other the main components on which a car seat is built. The main elements that compose the seat are the ones designed to each body-part affected by a stress during the trip. Starting from the lower framework that manage the load, going on to the cushion and the back rest that support the body, until reaching the head rest that sustain the top, each component is properly designed to be able to behave in the best way during the trip. All the components are connected in order to provide customizable configurations that better adapt to the occupants and each of them is equipped with materials and devices required to behave properly in each condition that might arise.

The second step after problem clarification, i.e. after having applied functional analysis, is to search externally, aiming at finding existing solutions to both the overall problem and the sub-problems identified during the problem clarification step.
There are at least five good ways to gather information from external sources:

- Lead user interviews: i.e. interviewing those users of a product who experience needs months or years before the majority of the market. In this thesis work this analysis has been conducted during product planning phase for extracting customer needs;
- Expert consultation: for GT-PAD design, designers of other seats have been interviewed and also experts in modular architecture product (for example, the designer of space module has been interviewed. Special applications in fact is the third business unit inside Sabelt SpA, which sharing with other all the other business units resources and knowledge);
- Patent searches: patents have not been found on seat;
- Literature searches: several books and readings have been consulted, from modularity to material selection ones;
- Competitive benchmarking: already conducted during QFD analysis.

The third step is dedicated to finding knowledge and ideas internally: for GT-PAD's idea generation several brainstorming sessions have been set (one every week, starting from May to July, when the idea was finally freezed), both in group than individually between the two designers that completely followed the project.
The fourth step of concept generation analyses the solution found.

4.2 Detailed design and product architecture

According to a widely accepted definition given by Ulrich [56], product architecture is defined by *the relationships between its functional elements, the mapping among functional elements and physical components and the interfaces among physical components.* Using this definition, the focus now extends from components to functional elements and centers on the interface between the function tree and the lower echelon of the product Bill of Materials. In GT-PAD case, the architecture of the product is modular, i.e. it is characterized by functionally independent components. Each component therefore is in charge of implementing a single function, and each function is fulfilled by a single component. More specifically, the architecture of GT-PAD is a bus-based modular architecture, in which components will not be directly connected with each other, but through a common component (called bus) using a standardized interface, that in our case is the shell of the seat. In this case the interface of the architecture is coupled, i.e. a change in one of the connected components will propagate to the other components and it will require a partial redesign.
What it is important in this thesis work is the underlining concept that the type of architecture that is used by a firm casts a strong influence on aspects that are relevant at both tactical and strategic level. Moreover, a modular architecture enhances localized performance variables, because it means that it is required a system with the objective of enhancing localized performance variables and not the totality of the system itself. Given the complex web of relationships between functional elements, the designer will look for an aggregation of the components into modules that are relatively independent of one another and that might exhibit significant interdependencies within. For this reason, this activity can be performed either intuitively using functional block diagrams and visually identify "chunks" of components (or modules) that exhibit a high degree of interrelationships - this type of approach has been followed for GT-PAD detailed design. For doing so, intercomponent relationships is represented with adjacency matrices: the relationship $a_{ii'}$ represents the strength of relationship between component i and component i'. The type of relationship searched in this thesis work is a functional interaction, in order to finding harmful or beneficial relationship between components. Three macro components have been identified for GT-PAD: fabric material, shell material and kit pads material; the degree of interrelationship is given by a 1 to 4 range. The first adjacency matrix for GT-PAD is shown below:

	Covering fabric	Foam cushion	Seat base	Fibraglass structure	Safety belt	Fixing frame
Covering fabric		3	3	3	1	
Foam cushion	3			3	2	
Seat base	3			3		4
Fibraglass structure	3	3	3			3
Safety belt	1	2				
Fixing frame			4	3		

Figure 4.9: First adjacency matrix

The score obtained using chuncks is given by the the sum of the value internal to chuncks minus the value external to them; in our case

$$Score = (3 \times 2 + 2 \times 1) - (3 \times 4 + 1 \times 1 + 4 \times 1) = -9 \tag{4.1}$$

As we can see the score is very negative: sorting the components in a different order we obtained a second adjacency matrix.

	Foam cushion	Seat base	Fibreglass structure	Covering fabric	Fixing frame	Safety belt
Foam cushion			3	3		2
Seat base			3	3	4	
Fibreglass structure	3	3		3	3	
Covering fabric	3	3	3			1
Fixing frame		4	3			
Safety belt	2			1		

Figure 4.10: Second adjacency matrix

obtaining, this time, a score equal to:

$$Score = (3 \times 5) - (4 \times 1 + 3 \times 1 + 2 \times 1 + 1 \times 1) = 5 \tag{4.2}$$

In this way, the adjacency matrix score is positive and states that, the relationship between the first four elements is strong (i.e. the relationship between shell materials and kit pad materials), meanings that these four elements are the main ones for defining the correct product architecture, leaving safety belt and fixing frame as a secondary architectural choice.
Modular product architecture has been defined by Ulrich and Eppinger [56] as an architecture with these properties:

- Chunks implement one or a few functional elements in their entirety;
- The interactions between chunks are well defined and are generally fundamental to the primary functions of the product.

Modular architecture is one in which each functional element of the product is implemented by exactly one physical chunk and in which there are a few well-defined interactions between the chunks. Such a modular architecture allows a design change to be made to one chunk without requiring a change to other chunks for the product to function correctly; moreover chunks may also be designed quite independently of one another.
Product architecture choice is an important decision that links several issues of importance to the entire enterprise: product change, product variety, component standardization, product performance, manufacturability, product development management. The architecture of the product therefore is closely linked to decisions about marketing strategy, manufacturing capabilities and product development management. For every part of the enterprise has been analysed pro and cons of modular product architecture:

- For product change, a modular architecture allows the firm to minimize the physical changes required to achieve a functional change;
- Product variety refers to the range of product models the firm can produce within a particular time period in response to market demand. Products built around modular product architectures can be more easily varied without adding tremendous complexity to the manufacturing system;
- For component standardization it is intended the use of the same component or chunk in multiple products; if a chunk implements only one or a few widely useful functional elements, then the chunk can be standardized and used in several different products;
- Product performance means like a product implements its intended functions; in product modularity every module implements one function;
- For manufacturability issues, design-for-manufacturing (DFM) strategy involves the minimization of the number of parts in a product through component integration;
- In a modular architecture,one group of few people is assigned to design a chunk deals with known, and relatively limited, functional interactions with other chunks.

4.3 Engineering design process

GT-PAD has been defined as a modular product and product modularity design is supported by MFD - Modular Function Deployment technique. MFD starts with an analysis of customer needs that is very similar to the one performed in QFD. Each of these customer needs is then associated to a degree of relevance of modularity, i.e., a 1–9 score expressing the degree with which modularity might contribute to the satisfaction of each customer need. In turn, this potential contribution of modularity can be systematically analysed with respect to a number of modularity drivers. After this first step, the product is analysed from a functional perspective, leading to a list of technical solutions; at this point, the core step of MFD is performed by developing the Module Indication Matrix (MIM). The MIM matrix is a table that represents the relevance of each modularity driver (in rows) to each technical solution (in columns), with the same 1, 3, 9 scale that has been already used in QFD; summing up these scores across columns, designers had the possibility to understand which of the modularity drivers appear to be more relevant as technical solution and conversely which clusters of technical solutions that are relevant to a same modularity driver.
MFD is, in summary, a systematic procedure consisting of five main steps:

1. Clarify Customer Requirements;
2. Select Technical Solutions;
3. Generate Concepts;
4. Evaluate Concepts;
5. Improve each Module.

Step 1 consists in inserting "modularity" as technical solution directly in QFD matrix; the result of customer interview is shown in the image below:

	Customer Requirements / Technical Characteristics	Degree of importance	Relative importance	Modularity	Weight	Friction coefficient	Material lightness	Stability	Comfortability	Foam density	Aesthetic	Easy adjustments	Breathable materials	Robustness	Safety	Ergonomy	Rigidity
				A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	A seat that is comfortable	4	12,9%		▲	◆		▲	●	▲		●		▲	◆	●	▲
2	A seat with easy maintenance procedures	3	9,7%	▲	◆						▲				◆		
3	A seat that can be customized	5	16,1%	●									▲			◆	
4	A seat where security harnesses fit well	4	12,9%			▲		◆		▲							▲
5	A seat with high technical characteristics	4	12,9%	▲		●	●		●		▲	◆		▲	●	▲	
6	A seat with hight safety factor	3	9,7%			▲		●		◆			◆		●		▲
7	A seat made by innovative materials	4	12,9%	●	▲	◆			▲	●			●		◆		◆
8	A seat with an high quality of the finish	2	6,5%	◆						▲	●					◆	
9	A seat that is not bulky	2	6,5%	●	▲		●	●				◆		●	▲		◆
	Total	31	100,0%		↓	↑	↑	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑

	Current Model	Competitor 1 (MOMO)	Competitor 2(OMP Racing)	Competitor 3(Sparco SpA)	Targets (new model)	Improvement ratio	Strength	Absolute weight	Relative weight
1	3	3	4	4	4	1,33	1,2	6,4	8,2%
2	3	2	3	3	4	1,33	1	4,0	5,1%
3	1	1	1	2	5	5,00	1,5	37,5	47,9%
4	4	3	4	4	4	1,00	1,2	4,8	6,1%
5	3	3	4	3	4	1,33	1,2	6,4	8,2%
6	4	4	4	5	4	1,00	1,2	3,6	4,6%
7	2	2	2	3	4	2,00	1,3	10,4	13,3%
8	3	3	4	4	4	1,33	1,2	3,2	4,1%
9	3	3	4	3	3	1,00	1	2,0	2,6%
								78,3	100%

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
Technical Importance	3,935	1,065	2,097	1,742	1,968	2,710	2,226	1,258	1,355	1,742	1,355	2,581	1,774	1,258	27,065
Technical relative imp.	14,5%	3,9%	7,7%	6,4%	7,3%	10,0%	8,2%	4,6%	5,0%	6,4%	5,0%	9,5%	6,6%	4,6%	100%
Absolute weight	6,17	0,77	1,27	0,97	0,95	1,87	1,79	0,77	0,84	2,68	0,72	1,49	1,50	0,73	22,52
Relative weight	27,4%	3,4%	5,6%	4,3%	4,2%	8,3%	8,0%	3,4%	3,7%	11,9%	3,2%	6,6%	6,7%	3,2%	100%
Unit of Measurement	Y/N	kg	-	kg/m^2	-	-	kg/m^3	Y/N	unit	Y/N	-	-	-	kN/m	
Current Model	N	13	-	245	-	-	28	Y	2	N	-	-	-	65	
Competitor 1 - Alpinestars	N	12	-	230	-	-	33	Y	2	N	-	-	-	70	
Competitor 2 - OMP Racing	Y	12	-	215	-	-	26	Y	2	N	-	-	-	68	
Competitor 3 - Sparco SpA	Y	11,5	-	250	-	-	30	Y	2	Y	-	-	-	60	
Target model	Y	10	-	200	-	-	25	Y	2	Y	-	-	-	50	

Figure 4.11: QFD matrix with modularity as technical solution

Using modularity as technical solution, customer requirements remain the same (A seat that can be customized firstly, followed by A seat made by innovative materials) but technical characteristics totally change: modularity obtained 14,5% of technical relative importance, followed by comfortability, that was the most important technical characteristic in the previous QFD. For this reason, modularity has been found as a

good technical solution during detailed design phase.
Step 2 consists in breaking down the product into functions and to match them with corresponding technical solutions: this step is also called functional decomposition. A good modular design has one module satisfying only one function and the interactions between modules could be considered as minimal and incidental and can be treated as noise factors. The image below shows GT-PAD functional decomposition:

	Modularity	Weight	Friction coefficient	Material lightness	Stability	Comfortability	Foam density	Aesthetic	Easy adjustments	Breathable materials	Robustness	Safety	Ergonomy	Rigidity
Ensure ergonomy						X			X				X	X
Good driver position	X		X			X			X				X	X
Safety			X		X	X						X		
Stability	X													
Comfortable positioning	X				X	X			X					
Head protection	X	X						X				X		
Adaptability to driver's body	X			X			X	X		X				

Figure 4.12: GT-PAD functional decomposition

Aggregating technical solutions lead to select which functions have to be implemented most: all the functions have at least two technical solutions that cooperates; modularity instead contributes to all the functions of the product and has to be implemented with major accuracy.
Step 3 is the core step of MFD and consists in creating the Module Indication Matrix, MIM, that is a QFD-like tool, in which each function carrier (technical solutions) is assessed sequentially against every module driver, for each column, vertically down through the matrix.
There are several module drivers that can be found during the entire product life cycle. During product development and design phases module drivers are:

- Carry-over, i.e. a part of a product, or a sub-system of a product, that can be re-used;
- Technological evolution means a technological shift during its life cycle as a result of expected or unexpected customer demands changing;
- Planned design changes is a product planning change at a specific time.

In order to handle product variation and customisation effectively one should strive to allocate all variations of a technical specification for variants to one or a few parts of the product; moreover, also styling module has to be considered because several products are strongly influenced by trends and fashion.
During production phase, the most important module driver is to find parts and sub-functions that can be common units and used throughout the entire assortment of products; furthermore, product modularity influences process and/or organisation re-use, meaning that the shop floor work, for example, can be organised in different ways in different module areas. In an organisation like this it is also easier to re-use process equipment and skills.
For quality issues, the most important module driver is the separate testing of functions, because each module can be tested before it is supplied to the main flow: this gives

the possibility to reduce feedback times.
For purchasing aspects, modularity gives the possibility to purchase complete standard modules (blackbox-engineering) from system specialist vendors instead of individual parts from sub-contractors. Modularity means that fewer parts are needed to build up the assortment; this, in turn, means less material to ship, with consequently lower logistic costs. Dealing with one major supplier instead of many minor ones also allows the administration cost of the logistics to be lower.
For after-sales purposes, modularity improves a quicker maintenance service, gets the possibility to upgrade the product more easily and enables a high degree of recycling, limiting the number of materials used in each module. A major emphasis is also given to sustainable design and a growing interest for environmental issues.
Each module driver described above can be used as the base for a systematic evaluation of the sub-functions within a product. For this purpose, a matrix, in which every sub-function can be assessed against the module drivers, can be formed: in this way MIM matrix can be finally completed.
It's good to notice that MIM matrix works as a basis for analysing the possibility of making functional integration in order to avoid the risk of getting a product that simply consists of stapled functions: the MIM in fact works for integration or grouping of sub-functions.
The MIM matrix for GT-PAD is illustrated in the image below:

	Sub-function (techn. solution) \ Module driver (function carrier)	Complete kit-pad	Fibreglass shell	Foam	Anti-slip fabric	Fixing frame	Belts	Air-ducting system
Company specific	Financial benefit		▲		◆			
	Design continuation		●	▲			●	
Development and Design	Carry over					●	●	
	Technology push			●	▲			▲
	Product plan	●						◆
Variance	Technical specifications			▲			▲	
	Styling	●						
Production	Common units		▲	▲	▲	◆		▲
	Process/Organization	▲						
Quality	Separate testing	●	●			●	●	
Purchase	Black-box engineering	▲				▲	▲	
After-sales	Maintenance	●		◆	▲	●	●	
	Upgrading	●					◆	
	Recycling			◆				
	Weight of module driver vertically summarized	51	24	20	10	31	43	7
	Module candidate	✓				✓	✓	

◆	1
▲	3
●	9

Figure 4.13: GT-PAD Module Indication Matrix

Unique module drivers that are highly weighted indicate that the sub-function in question has a complicated requirements pattern and is likely to form a module by itself: in GT-PAD is the case of complete kit-pad sub-function, with the highest weight of points. There are also few low weighted module drivers, on the other hand,that indicate

that the sub-function in question might be easy to integrate or to group together with other subfunctions: this is the case of fixing frame and belts, that can be considered as external part of the proper seat - even if they are fundamental - but they can be developed together externally to the GT-PAD production process.
Step 4 of MFD consists in evaluate the resulting effects in order to assess the proposed changes and to compare with the earlier situation. Firstly, an evaluation of interface connections it the most important factor for the selection of the concept; the shell of GT-PAD is a fixed interface structure that connects modules in a product and gives them stability. The identification of interfaces, moreover, influences also assembly and production time: having only one main interface simplifies the seat construction at the maximum level.
In this phase, furthermore, several questions of economical nature occur: Is it possible to predict and calculate the effects of a well designed modular product? or What are the implications for the total life cycle costs? for example. In fact preliminary evaluations have to be made even in the conceptual phase since economic factors are of crucial importance in the design of modular systems. Designer estimated in fact the production cost of the individual modules and their relative effect on the cost of the modular system as a whole, in order to minimise the costs of a modular system, not only the modules themselves but also the cost of their interactions. For a good economic metrics evaluations, [51] indicates metrics and rules that may be used for the evaluation of a proposed modular product design, according to the table below:

Life phases	**Product characteristics**	**Metrics/rules**
Lead time in development	Interface complexity	$IC = \frac{\sum_{i=1}^{N_m-1} T_{Ass}}{3}$
Development cost	Share of carry over	n° of carry over parts
Development capacity	Share of purchased modules	Supplier development module
Product cost	Assortment complexity	$AC = \sqrt[3]{N_m \times N_c}$
System cost	Share of purchased modules	Total cost share
Lead time	Number of modules in product	$L = \frac{N_p T_{norm}}{N_m} + T_{test} + (N_m - 1)T_{int}$
Quality	Share of separetly testing modules	Probability not contain defects
Variant flexibility	Multiple use	$E_{var} = \frac{N_{var}}{N_{mtot}}$
Service/Upgrading	Functional purity in modules	One module=one function
Recyclability	Material purity in modules	Low number of different materials

Table 4.1: Economic metrics evaluation for good modular design

For Interface Complexity IC, the variable N_m states the number of modules in one product variant and T_{Ass} is the time of assembly needed for every module. In our case N_m is equal to 1 and the time of assembly for every pad, including attaching well the pad and fitting with the driver, founding the correct driver position, is 75seconds, obtaining IC equal to 3. The ideal IC is given by the formula $IIC = \frac{(N_m)10}{3}$ that, in

this case, is equal to 33, so we have obtained, choosing one module a lower lead time in development that leads to lower development cost.
For development cost, the number of carry over parts are analysed and in GT-PAD case the number of parts that can be carried over for next seat generation are: kit pad, fixing frames and belts, giving the possibility to savings all these cost for the future.
For development capacity metric, it's important to understand that if each module could be totally been supplied by the supplier, not affecting purchasing company strategy and capacity, the module has reason to exist. This is the case of kit-pads, that will be totally supplied by Espa supplier.
Product cost metric includes N_m as the number of modules in one average product variant and N_c as number of contact surfaces between modules in one product. N_c is difficult to estimate and can be considered as the total assembly time over an interface over 3, obtaining 25, already used in interface complexity computation. Our metric for GT-PAD is equal to $AC = \sqrt[3]{7 \times 25} = 0.33$ where the ideal Assortment Complexity should be $AC = 1.5\sqrt{N_p} = 1.5(\sqrt{7}) = 3.96$. 7 is the number of modules in one product (in our case the number of pads in one seat) and, obtaining a lower AC states that the modularity design leads to reduce cost respect to the old one.
For share of purchased cost it is meaning that it should be considered costs occurred during purchase costs, costs for production planning, quality control costs, production engineering costs and logistics costs. In summary, the higher the share the lower the system costs: in our case purchase cost and logistic cost diminishes because the supplier includes in the purchase cost of the kit pad also the logistic cost of transportation from Tunisy to Italy, leading to a lower logistic expenses.
Lead time metrics is more complex and, deriving the formula, it is possible to obtain a minimum vale: $\frac{dL}{dN_m} = -\frac{N_p T_{norm}}{(N_m)^2}$. As a rule of thumb T_{norm} is equal to 10 seconds, N_m in our case is equal to 7, N_p is the 60-70% of parts that can be count in a possible old generation of the product, and in our case is 20 circa. The minimum lead time obtained is so $\frac{dL}{dN_m} = -\frac{20 \times 10}{(7)^2} = 4{,}081$. The ideal number of modules is so rounded to 4: in GT-PAD we decided to design 3 modules, lowering also in this case, the costs.
Quality probability is also one important issue for modules: if the defect probability is lower respect to old product the module can be considered as a good choice. In GT-PAD case, defect probability has been stated at 10%, in an equal manner to all other Sabelt's seats: in this case modularity cannot be considered as an advantage.
Variant flexibility can be simply calculated as the relation between the number of product variants and the total number of modules needed: a high value indicates high similarity between product variants, which has many advantages: fewer set ups, fewer tools, simpler order planning. In GT-PAD seat, the number of product variants are 3 and the number of module needed is 1: the variance is equal to 3. 3 is not a so high variance value but respect to the variance equal to 1 of old models could be considered as a good implementation design.
For the last two life-cycle phases, they have been already discussed during MIM matrix.
The last step of MFD is the potential improvement of each module. In this thesis work, the use of kit-pads enhances the development capacity enlargement with suppliers and the variant flexibility of the product but the improvement of the module is not a matter of this work.

Chapter 5

Prototyping & testing

Prototype is defined as *an approximation of the product along one or more dimensions of interest.* [56] Under this definition, any entity exhibiting at least one aspect of the product that is of interest to the development team can be viewed as a prototype. This definition deviates from standard usage in that it includes such diverse forms of prototypes as concept sketches, mathematical models, simulations, test components and fully functional pre-production versions of the product. Prototyping is so defined as the process of developing such an approximation of the product.
Prototypes can be usefully classified along two dimensions. The first dimension is the degree to which a prototype is physical as opposed to analytical. Physical prototypes are tangible artifacts created to approximate the product; analytical prototypes represent instead the product in a non-tangible manner, usually mathematical or visual. In this thesis work both physical and analytical prototypes sample have been used for testing the product before production starts. The second dimension is the degree to which a prototype is comprehensive, i.e. a prototype that includes all the attributes of the product as opposed to focused, where a prototype implements one or few product attributes; in our case the thesis focused more on comprehensive prototype.
Prototypes are useful for learning first of all, for communicate among top management, vendors, partners, customers and investors, for improving the integration between all the parts of the product and lastly for demonstrate that the product has achieved a desired level of functionality. In general analytical prototypes are more flexible than physical prototypes, because they contain several parameters that can be varied in order to represent a range of design alternatives; physical prototypes instead are used for detect unanticipated phenomena, as it happened in this thesis work.
In our case, prototyping and testing are necessary phases in order to be compliant with rules explained in the homologation law and with static and dynamics tests done for obtaining the homologation release. 3D CAD models and physical prototypes enrich the prototyping and test phase.

5.1 Homologation requirements

Homologation is the granting of approval by an official authority in order to assure that they meet standards for such things such as safety and environmental impact. In case of seat and seat belts, the main business of Sabelt SpA, homologation certificate is required and is necessary for every product that will be sold on the market, because they have to assure a certain standard level of safety. For this reason, the Federation International de l'Automobile (FIA) issues several rules to be respected before obtaining the certification: every manufacturer is so obliged to take care of these rules and to be compliant with. FIA regulations are necessary for encourage and implement the adoption of common regulations for all forms of motor sports and series across the world; in fact FIA has several regulatory norms divided for circuit (for example Formula One, Formula E or Karting), for rallies (African or Asia-Pacific are two cases) or for off road (such as autocross or rallycross).
Moreover, FIA issues also the rules for the products that will be mounted on cars, whatever the use of the car is. This is our case and, more specifically, the FIA rules for racing seats depends on the materials with which shell seats are made and in which way the seat is fixed to the body of the car. In GT-PAD case, Standard 8855-1999 will be used, using a fibreglass shell with lateral fixing supports.
The Standard 8855-1999 states that:

- The minimum required weight will be calculated by decreasing the recorded weight by 10% but not increasing it - this minimum required weight will be used during the post-homologation tests as a mandatory criterion of compliance;
- A dynamic tests shall be carried out using a catapult sled in the rear and lateral crash directions - further explanation will be done in next section 5.2;
- When tested the structure of the seat myst remain intact, with no fractures, separation or visibile cracks on both sides of the structure.

The homologation procedure states that the models of seats to be homologated shall be tested to the present standard by a test house approved by the FIA (internal or an external company), the report should be submitted to ASN (Autonomous System Number) of the country of the manufacturer which shall apply to the FIA for the homologation certification. After approval, a FIA label is issued indicating the manufacturer's name, the model of seat and the homologation reference number, including the year of production; following completed homologation the FIA will publish details of newly homologated seats in Technical List 12, published in the FIA web page (www.fia.com).
Also the label has several characteristics to be respected: it must have a 84mmx34mm dimensions and must be stick in a easy visible place, made with a white background with bold black text. The label should report FIA Standard reference name, manufacturer's logo, seat model reference, FIA homologation reference number and year, month and year of manufacture of the seat, date of the end of validity (only the year) preceded by the words "Not valid after:" and serial number.
Furthermore, FIA establishes also seat life, that corresponds to 5 years from the year of manufacture (a seat manufactured on 1 January 2014 will be "Not valid after 2019"; likewise, a seat manufactured on 31 December 2014 will be "Not valid after 2019", so what is important is the year of manufacture, not depending from the month). An

extension of up to 2 further years may be authorised where the seat has been returned to the manufacturer for re-validation: the extensions will be indicated by an additional label affixed to the seat.

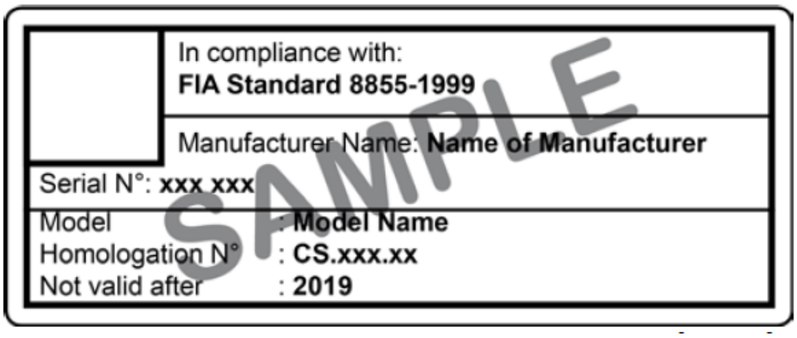


Figure 5.1: FIA label sample

It should be noted that when applying for the homologation, the manufacturer undertakes not to modify the design, materials and fundamental method of production of the product. The only parts that may be modified without consulting the FIA are those explicitly specified in the FIA standard applying to each product. The FIA could also conduct one or more post-homologation test; if failed, the manufacturer will be notified by registered letter of the non-conformity of his product and it has a second possibility, within 20 days, of providing a new sample that can be re-tested. If this sample is again found not to comply with the standard,the non-conformity of the product will be established on the solegrounds that the irregularity of this single sample has been noted. If the non-conformity of the product is established, the FIA will invoice the manufacturer, via his ASN, for the entire costs occasioned by these control tests: these include the costs of purchasing the product, the costs of the tests, and a fixed sum of 2500 CHF for the services and travel expenses of the FIA Observer. If the sample instead is found to comply with the standard, the conformity of the product will be simply re-established.

5.2 Static & dynamic tests

Static prototyping tests are useful for testing the validity of the product after detailed design and product architecture have been decided. Moreover, physical prototypes can be developed in steps, from preliminary (or alpha) prototypes, in which components and manufacturing processes can be significantly different to the final ones, intermediate (or beta), in which components and processes are similar to the final ones, and pilots, which are built using final components and production processes. In this thesis work one alpha prototype for static (or physical) testing has been made, followed by several dynamic tests.
Also virtual prototyping could be considered part of static tests and it occurs before physical prototyping. CAD (Computer-Aided Design) software is been used in this thesis work and after a stress simulation through Finite Element Method (FEM) the alpha physical prototype has been made and tested with potential customers.
The first step occurred using CAD using Catia V5 as a software: as we can see in the image below a CAD drawing has been made from scratch to final design, coming up with the shell before and then with kit pad.

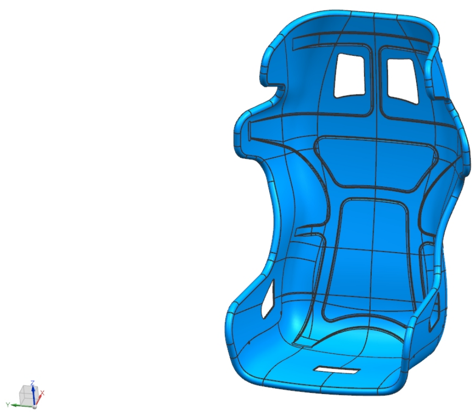


Figure 5.2: Shell CAD design

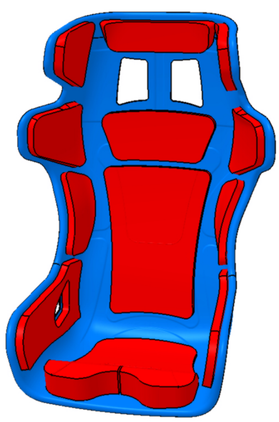


Figure 5.3: GT-PAD with kit pad design

After design can be considered concluded, FEM analysis has been done in order to analyse stress solicitations and probable break points. The FEM analysis is necessary because it subdivides a whole domain into simpler parts for better represent a complex geometry and for capture a local stress effect (in our case).
Regarding physical alpha prototyping, the 25 July 2017 a mock-up for GT-PAD has been made composed by styrofoam. According to designer idea, the mock-up should be bigger than the real seat will be produced later. In reality, when the mock-up has been proposed to a potential customer (Alpine) the styrofoam seat turned out as much smaller and with a very uncomfortable position of the driver. In the image below you can see the alpha mock-up prototype.

Figure 5.4: Alpha prototype mockup seat

The physical prototype shown in the images below revealed several problems in the design phase and in the mock-up itself: in the first image the shoulder protection height is wrong for a potential customer with normal height and weight, i.e. the most probable customer at all. In the second image the same customer, with its helmet, has not the correct ear protection as it should be. In the third image, a potential customer that represent the 5th percentile in height, i.e. a customer that has a superior height to the average, is not protected at all from the seat: his shoulders are at ear axis position and his head is totally out of the seat. This driver position is neither comfortable but above all it is not sure. In the last image a potential customer, as the first customer in image 1 and 2, is not protected at all by the kit pads, even if he chose the M size (so the kit pad with the most density foam ever and the most expanded). In this case the designer were totally surprised and grateful of having tested this alpha prototype: from their estimation, the mock-up should be larger than the real seat will be put in production but after the test, their convictions were dispelled.
In conclusion, the physical prototype helped designers in revising the project work and, at the end, they modified:

(a) *Customer 1 - Wrong shoulder protection*

(b) *Customer 1 - Wrong protection helment position*

(c) *Customer 2 - Not safe at all*

(d) *Customer 3 - Not comforting seat*

Figure 5.5: Alpha physical prototype with customers

- **Shoulder height:** a different position of the shoulder has been set, leading to a final 672mm from the bottom of the seat (initially this distance was 630mm);
- **Ear protection adjustment:**the 'ears' of the seat have been translated ahead for ensuring a better head protection;
- **Kit pad redesign:** the density of the foam has been changed, using a different kind of foam, redesigning also the pad shape and the percentage of foam inside it.

Regarding dynamic tests instead, it is the homologation norm itself that set the rules for them. Specifically, norm 8855-1999, for competition seat, said that the dynamic tests shall be carried out using a catapult sled in the rear and lateral crash directions and a 50th percentile Hybrid-II or Hybrid III dummy shall be used, firmly maintained in the seat by a safety harness with a minimum of 4 points homologated by the FIA. The seat shall be positioned to comply as closely as possible with the standard position shown in drawing 5.6 and any differences between the standard position and the real position shall be mentioned in the test report; moreover, the position of the footrest shall be such that the backs of the dummy's thighs are in contact with the edge of the seat.

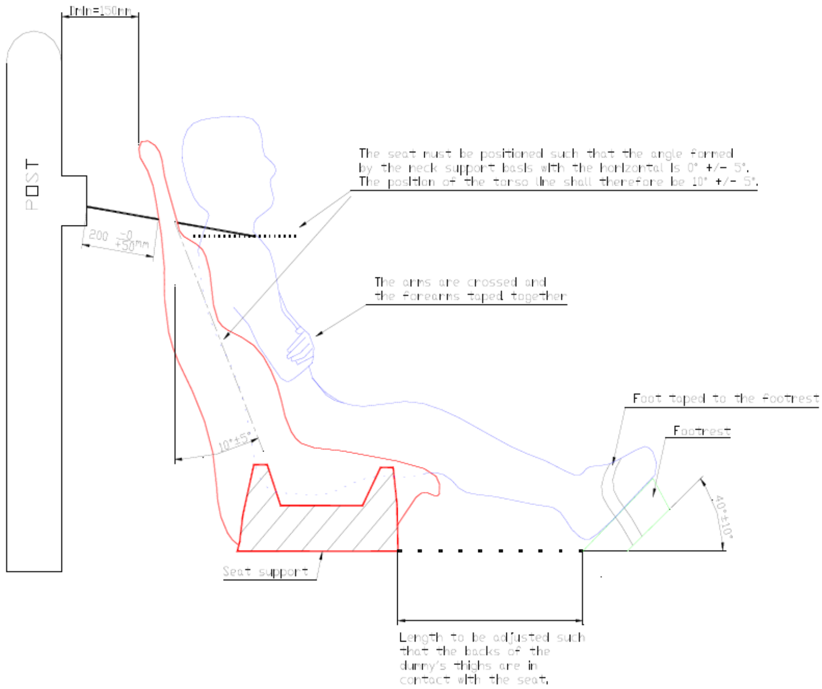


Figure 5.6: Dummy standard position

The most important dynamic test is the sled test, that is composed by three different impacts, in which the deceleration of the sled shall be measured by means of a class 60 measuring chain, in accordance with the SAE J 211 standard, and corresponding to the characteristics of the ISO 6487 standard.
The impacts are constantly monitored and must follow the acceleration/deceleration graph imposed by the norm. In details, the three impacts are:

- **Rearward impact:** a deceleration of 20g minimum measured over a minimum non-cumulated duration of 50 ms in which the deceleration curve is within the corridor of drawing 5.7;

- **Side impact:** a deceleration of 15g minimum measured over a minimum non-cumulated duration of 50 ms in which the deceleration curve is within the corridor of drawing 5.8;

- **Rearward impact:** a deceleration of 10g minimum measured over a minimum non-cumulated duration of 50 ms in which the deceleration curve is within the corridor of drawing 5.9

In total, two rear impacts occurred, with a side impact between them.

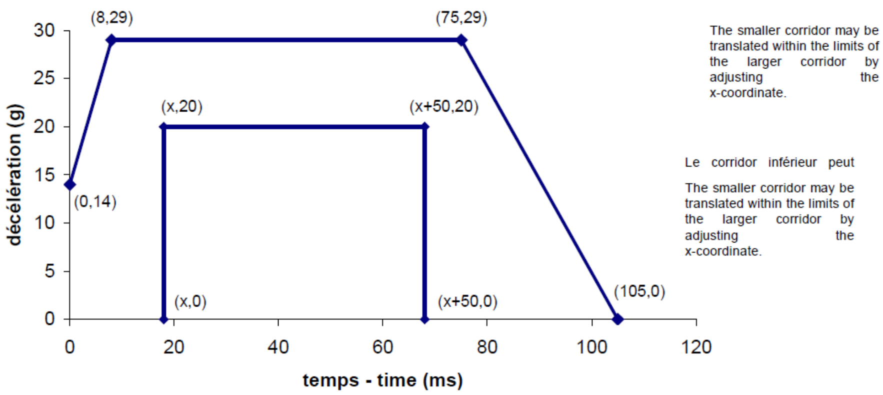


Figure 5.7: First rearward deceleration corridor - 20g

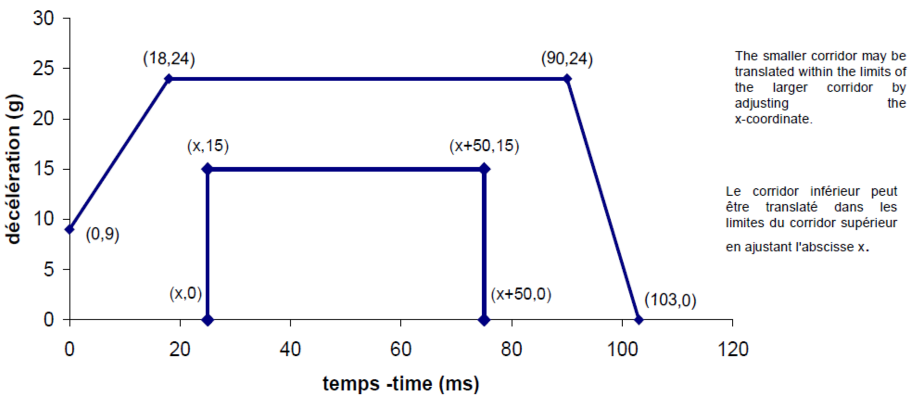


Figure 5.8: Side impact deceleration corridor - 15g

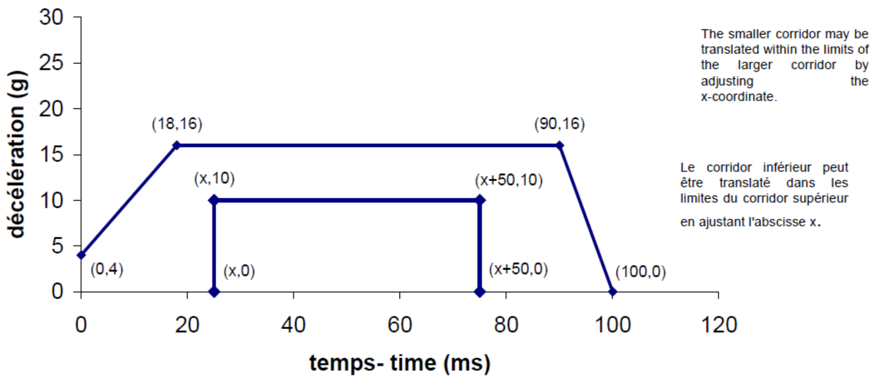


Figure 5.9: Second rearward deceleration corridor - 10g

The most important part of homologation, beyond obviously passing the three impact tests, is respecting the rule for screw mounting strips, because they must respect a specific stress area and they must be compliant with the rules in the norm. For this reason, the drawing of a mounting strip is more important than the drawing of the seat itself and the way in which bolts are inserted in the shell is checked several times by regulators. For this reason Sabelt SpA uses a mounting template as in figure 5.11 to avoid any risk.

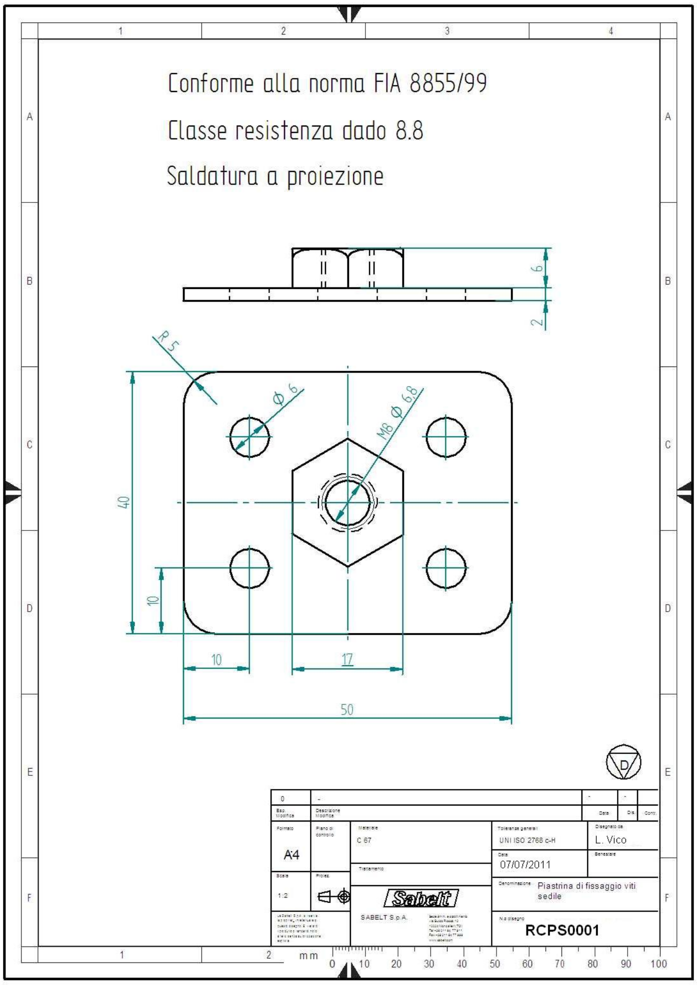


Figure 5.10: Screw mounting strip drawing

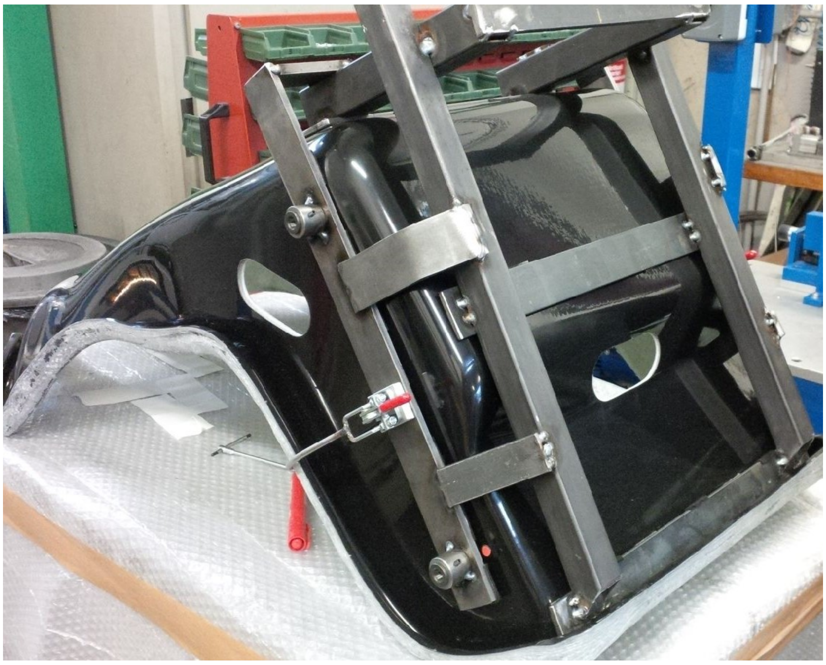


Figure 5.11: Mounting template

The dynamic tests, conducted at LAST-Politecnico di Milano, the nearest approved centre by the FIA for Sabelt SpA, has been done in this way:

- As pre-requisite, the dummy has been positioned in the seat according to the rule as in the figure 5.12;

- The first rear impact has been completed, obtaining a graph like 5.13, getting any damage;

- The side impact has been conducted, showing a graph like 5.14, not damaging the seat;

- The second and the last rearward impact has been launched, recording a slider like in figure 5.15, demonstrating finally that the seat remains unbroken and without any injuries.

Finally, the homologation label has been stitched on the seat, reporting the homologation number, as it is shown in figure 5.16.

Figure 5.12: Dummy positioning during test

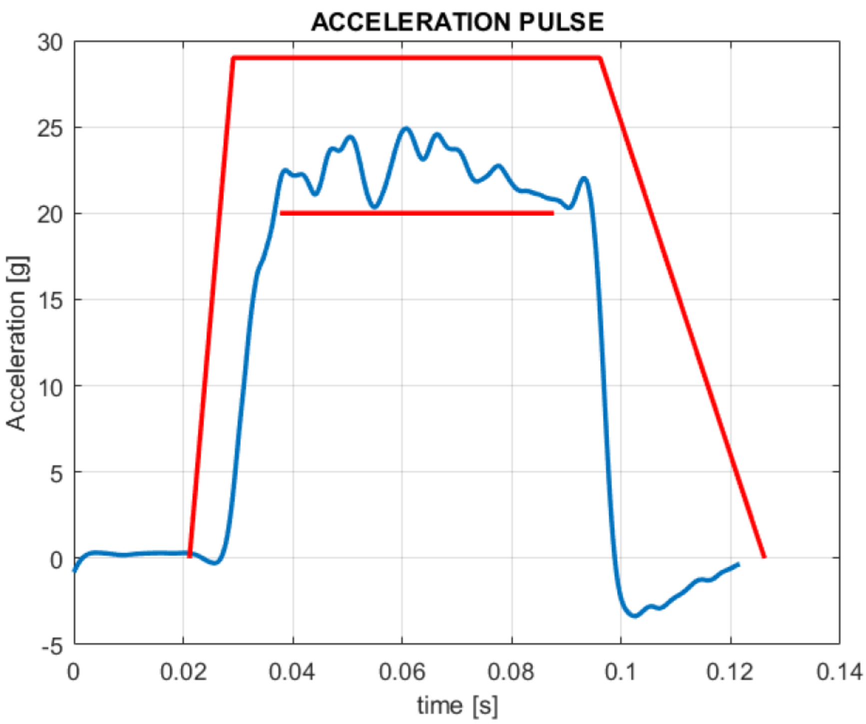


Figure 5.13: First rearward impact test result

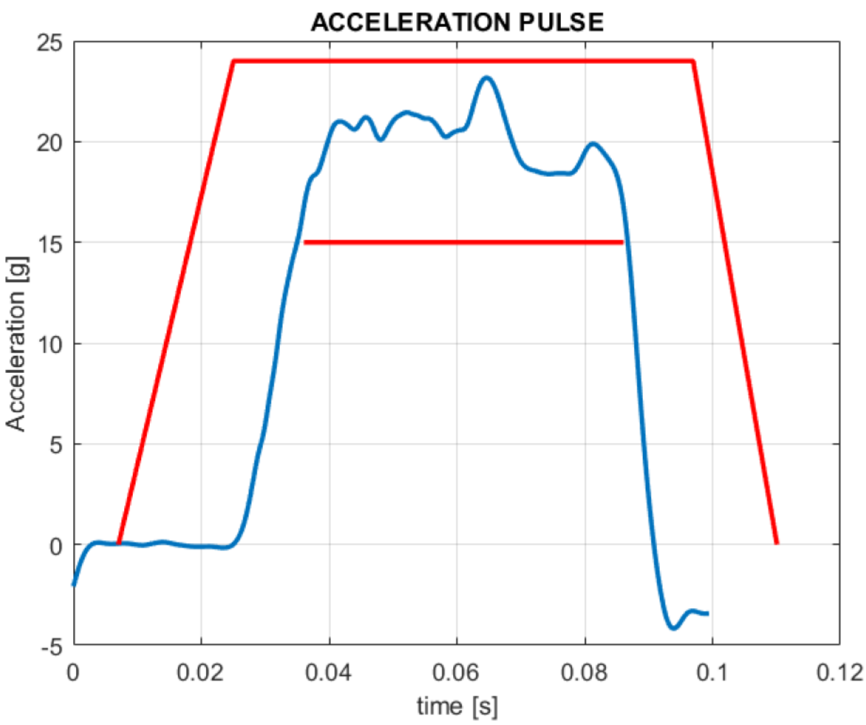


Figure 5.14: Side impact test result

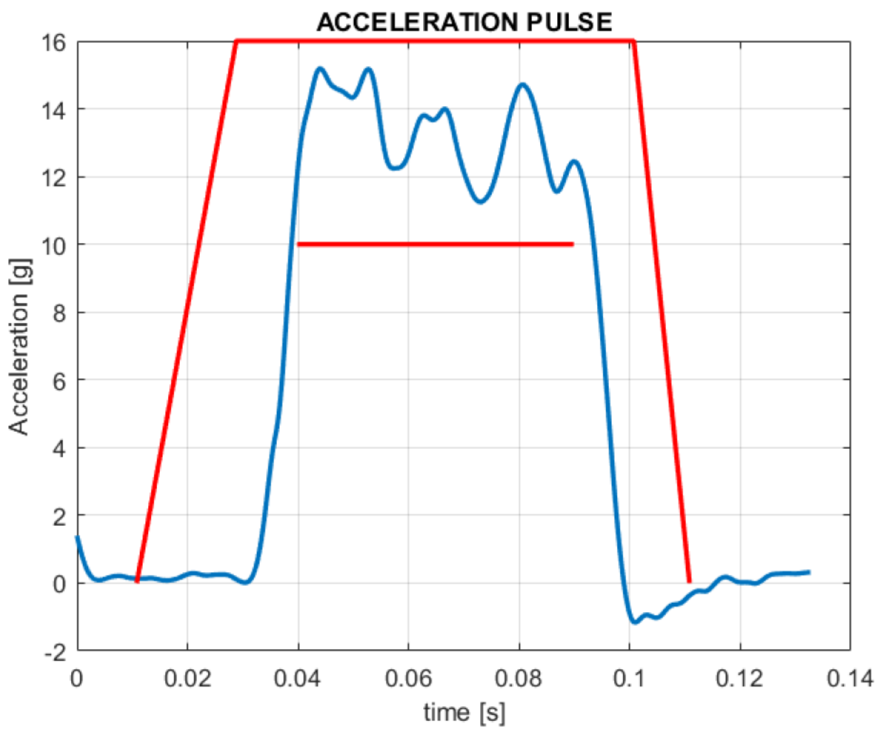


Figure 5.15: Second rearward impact test result

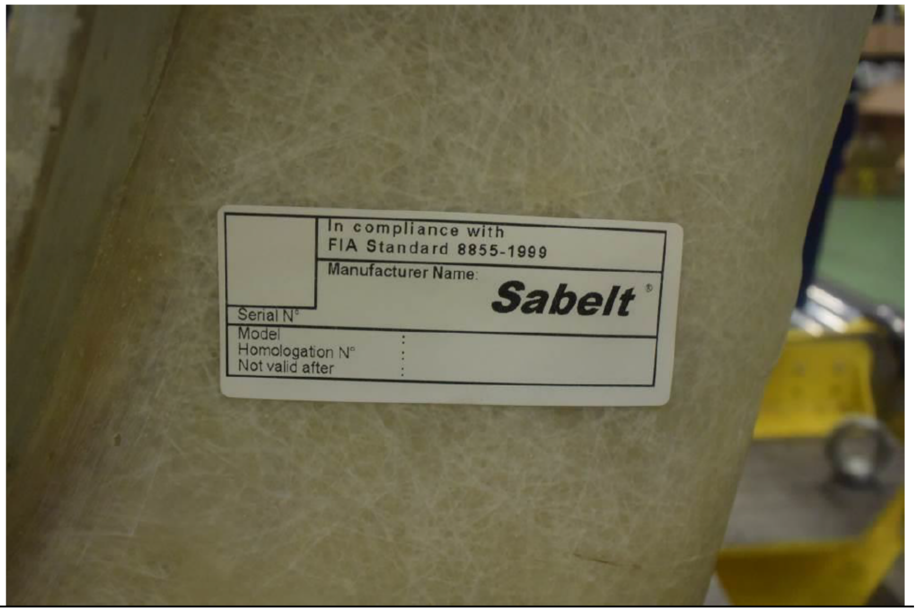


Figure 5.16: Stitched label after homologation

As it is shown in the graph, the acceleration pulse is always been inside the limits and GT-PAD obtained so the CS.391.18 homologation number, valid from January 2018 to December 2023. (the homologation number is extracted from the Technical List N° 12 of homologated seats).

Chapter 6

Process design

As has been already said, GT-PAD seat is a modular product, which characteristics are the common interface among all the elements of the seat itself (i.e. the kit pad) and the kit pads itself, that can be attached through the use of velcro to the saddled shell.
The manufacturing process, in this case, completely changes because now, in case of a modular product, the shell is bought as a standardized component by a well-know supplier, Sogrega Srl, that is an italian supplier that has a production facility in Tunisy. Also kit pads are bought externally by a foam manufacturer (Espa SpA) but then, both the shell and the kit pad are saddled in-house inside Sabelt SpA.
The saddling part of the product in fact allows personal customization and adaptability to every customer request: for this reason is the part developed internally to Sabelt SpA, because it allows to add the value to the final product.
The manufacturing process described below concerns the part of shell production from Sogrega supplier, the saddling part inside Sabelt SpA and all the parts concerning the after production phase, such as quality inspections and final testing.
It is good to say that the production of a seat depends, in general, from:

- Product type: the GT-PAD can be considered inside the middle market range seat type;
- Market segment: the GT-PAD as an estimated volumes of sales of 200-300 seats for the first year; in this way it can be classified as a product with wide sales prospects;
- Quality: in our case GT-PAD requires an high quality, due to the fact that is a racing seat, chosen by riched men who invest a lot of money in their hobbies.

6.1 Manufacturing process

The manufacturing process for GT-PAD can be divided in three different phases: Sogrega's shell production, Espa's kit pads production and Sabelt SpA saddling and final product assembling production.
Starting with Sogrega Srl, it is an italian supplier specialized in fibreglass manufacturing especially for the nautical sector: the manufacturing plant located in Tunisy is specialized in fibreglass and composite materials production.
The lamination process used for producing GT-PAD shell is totally different from RTM production. RTM, acronym that stands for Resin Tranfer Moulding, in fact is the most industrialized process used by company and consists in using a rigid two-sided mould set that forms both surfaces of the panel. The mould is typically constructed from aluminum or steel but also composite molds are sometimes used. The two sides fit together to produce a mould cavity. The distinguishing feature of resin transfer moulding is that the reinforcement materials are placed into this cavity and the mould set is closed prior to the introduction of matrix material. Resin transfer moulding includes numerous varieties which differ in the mechanics of how the resin is introduced to the reinforcement in the mould cavity. These variations include everything from the RTM methods used in out of autoclave composite manufacturing for high-tech aerospace components to vacuum infusion and to vacuum assisted resin transfer moulding (VARTM). The RTM process can be performed at either ambient or elevated temperature.
For GT-PAD, instead, there was the need to create a milled model of the seat (called improperly 'the male') made by Ureol, an epoxy resin used for CNC manufacturing processes, from which a master replicator is obtained. In this way the master is used for laminate directly on it and, in case of defects or model's breaking, the milled model from which the master has been obtained could be used again for obtaining a new master. From the master all the moulds for the future shell are obtained.
There are several phases for fibreglass lamination process for creating GT-PAD shell:

- Fabrics cutting: three different types of fibreglass materials are prepared before the lamination phase: the fabrics are different for density and elastic module. Fibreglass is thought as a fragile material but if it is spun at a diameter of less than a tenth of a millimetre it loses its characteristic fragility to become a material with high mechanical resistance and resilience. The glass fibre, that does not have all the defects of common glass, like microfractures during crystallization, reaches mechanical resistances close to the theoretical resistance of the covalent bond;

- Layer preparation: fabrics are impregnated with an epoxy resin before lamination operations;

- Lamination: after the mould has been prepared and gel-coatted, i.e. after the application over the mould of a special epoxy finishing paint (and this operation already took 2 hours), the lamination consists of overlapping several layers of fibreglass fabrics following the guidelines of the model and following the plybook. The plybook is a production plan that every manufacturer prepares specifically for every product. GT-PAD plybook has not been revealed by Sogrega Srl to Sabelt SpA. The lamination phase took more or less 45min / 1h and it depends from three factors: the type of resin used, the external temperature and the percentage of catalyst inside the resin. A catalyst is a chemical activator that reacts inside the resin, activating a heat process that lead the resin to harden faster, reducing lamination time; the percentage of the catalyst used is 2% over 1 kg of resin. Also the tunisian external temperature, that is higher respect to Italy, reduce lamination time;

- Shell extraction from the mould thanks to teflon tools. Teflon is the commercial name for the polytetrafluoroethylene, a synthetic fluoropolymer with the third-lowest friction coefficient, letting in this way to avoid adherence to any other kind of material. The roughing of the shell is done by hand by an operator to ensure the high standard quality of the final product;
- Perimeter finishing, through rounding of the edges and imperfections smoothing;
- Drilling operations for creating hole of bezel, according to a track previously drawn;
- Drilling operations for the correct positioning of screw mounting strips, using a mounting template, as already discussed in the previous chapter: the accepted tolerance is about 1 mm;
- Screw mounting strips glueing, with specific structural adhesive Plexus MA420. The minimum surface that allows a perfect bonding is between the range 0,8-1mm;
- Shell polishing, using anti-corrosive materials specific for fibreglass end products;
- Final testing, consisting in checking the distance between holes of right and left side, M8 screw test connection, aesthetic checks such as air bubbles or painting gun errors.

When the shell is then send to Sabelt SpA from Tunisy, Sabelt's quality department checks, within a sample, one shell according to an internal quality book. What is important is to check the weight of the shell itself: in fact, the weight, which is regulated in FIA rules, should be as the weight declared during homologation phase + 10% maximum. If the weight is not correct, the shell is send back to the supplier for further checks.
Considering cost, respect to Italy, the production in Tunisy has several advantages, as it is shown in the table below:

Cost driver	**Italy**	**Tunisy**
Labour cost	27€	10€
Inventory cost	4,5€/seat per day	1,7€/seat per day
General expenses	105 000€/month	32 000€/month
Lamination time	1,5h	45min
Taxes	22%	18%

Table 6.1: Cost evaluation between Italy and Tunisy

The total cost of one shell coming from Tunisy, including logistic costs, is 48€. Another shell, similar to GT-PAD shell, produced in Italy tends to cost 83€ circa, with an increase in cost of 42%.
For kit pads, the italian company Espa SpA produces foam shape for future kit pads, that will be covered with different colors of fabrics in Sabelt SpA. The kit pad are

designed using CAD model, then sent to the supplier that produce in total 12 pads for every shell, creating one complete kit pad. The total cost for one kit pad is 12€, splitted for the 80% on labour cost and 20% on material cost. The customization of kit pads could be obatined in three different variants: black, red and with a customized graphic, as it is shown below.

Figure 6.1: Kit pad alternatives

For the last part of the product, i.e. the saddling of the shell and of the kit pad, inside Sabelt SpA there exist specific stations where one operator saddled, using a foam as a guide, every shell by hand. The pictures in figure 6.2 explain better the production plant of Sabelt SpA.
In general, buying from an external supplier the shell and the kit pads helped Sabelt SpA to reduce labour cost and to introduce, for the first time, his role as a pure assembler of final product instead of a pure manufacturer of it. The value added given by this position is the customization features and the opportunity to exploit materials already used in-house and knowledge already developed for the production of other seat also on GT-PAD. For materials, such as leather or anti-slip fabric, the supply occurs in constant batches, following the EOQ production logic.

(a) *Sabelt's production lines*

(b) *Saddling trough foam support*

(c) *Sabelt saddling station*

(d) *Quality check*

Figure 6.2: Sabelt production plant

Chapter 7

Modularization strategies

Modular architectures and platform products do not only allow a quick change between successive product releases and product generations but also the simultaneous offering of differentiated product variants based on the common platform. This strategy can lead to three main advantages:

- The firm is able to address multiple horizontally and vertically differentiated market segments, with obvious benefits for its pricing power;
- In-platform components are produced in significant volumes,and the overall effort spent in developing the platform and product derivatives can also lead to economies of scale, because of the high volume that comes from all the product variants being offered.

Moreover, modular architectures can enable the offering of products characterized by combinatorial variety, in which a core product can easily be customized by adding or changing of number of components: this is proper the GT-PAD case. Going on even further, the firm may opt to fragment assembly operations and locate them closer to the customer; in this thesis work, in fact, the assembly of kit-pads is done by customer at its place. In fact, GT-PAD seat and kit-pads are sold separately and then assembled by customer.
Modularization strategies lead by modular architecture products give some pro and some cons in terms of:

- Standardization: because of component decoupling, modular architectures also make it easier to use standard components instead of purpose-designed ones; however this leads to additional costs, since having to choose among a limited set of standardized components will lead to over-dimensioning with respect to the needs of the specific application.
- Influence on the organization and supply chain: modular architectures lead to a significant decrease in the intensity of information flow between the designers that are in charge of developing each component. In project management terms, the project manager acts like a 'system architect', where his major focus is on the specification of components.

Modularization strategies can be described in three main categories: product modularity, production process modularity and strategic modularity.
Product modularity has already been described during design phase; however, according to [56], a product cannot be classified as strictly modular or integral, but it can be categorized relatively to other products in accordance with its degree of modularity. For this reason there's the need to assess the modularity degree during design phase. For product modularity exist three different levels:

- The final product level. It indicates the modularity degree of the final product along two criteria: the constituents of the final product are coordinated through standardized interfaces and each constituent performs only one product function. This is the case of kit-pads;

- The sub-system level: in this case complex product can contain components' interactions of different kind;

- The component level: the degree of component modularity depends on how many functions the component carries out and on the degree of its interdependency with other components.

In GT-PAD case the most important role on modularity can be seen on final product level.
Regarding Modularity in Production (MIP), although the concept of the platform is widely accepted and used in the automobile sector since 1960, the greatest changes regarding process flexibility and efficiency took place around the turn of the century, when platforms were reduced and standardised to develop a single common platform for different models within the same segment. In case of Sabelt SpA in fact, the GT-PAD seat, introducing modularity in production, allows to create a platform for developing also other shell for other seats. In the specific case, the racing seat are part of our area of interest and a platform, in case of seat developing, is made of a fixed running slide where a fixed mold of the shell is on it and can perform several shell. More specifically, the shell is fixed on the running slide but different saddling operations could be performed on the platform. The running slide used for improving modularity in production is shown in the image below 7.1.
For grouping resources and competences, the Sabelt SpA line of production moves from a customer-assembly line (only for racing seat, not for OEM production) to a product-assembly line. In this case, all the seats with a fibreglass shell have been moved to a single production platform. In this way the benefits obtained are:

- Better resource allocation;

- Less transportation cost;

- Reduction of errors propagation;

- More knowledge transfer.

For example, like in the image below, the fixed mold could reproduce the GT-PAD seat shell but also Taurus and GT3 shells.

Figure 7.1: Running slide for Modularity in Production

The main objective of such standardization was to rationalise the number of platforms and to share common components and systems among those models assembled on a single platform; this standardization strategy focused on aspects of product development like simplification of engineering and design processes, reduction of costs and development time and the ability to update products. It also aimed to take advantage of the economies of scale resulting from a greater number of common units per platform, such as savings on the purchase of components From a manufacturing perspective, the platform standardization strategy offered advantages for globalizing production processes because it allowed flexibility and cost reduction by using resources on a larger scale. From the technical point of view, such modular platforms are configured differently based on a single scalable design, allowing for changes in structural dimensions. This means that it is possible not only to assemble several models within a single segment (same size), as with the classic standard platforms, but also several models in different segments (different sizes).

The manufacturing networks approach consists in four main network strategic outputs: accessibility to supply sources, thriftiness ability gained by scale and scope economies, manufacturing mobility and learning ability which represent longer-term capabilities for network restructuring and operational flexibility (i.e. the possibility of transferring production among different plants).

In terms of production plan, the modular platform requires technical changes and investments both for the development of the platform and for the re-design of the production plant's processes and facilities. In terms of production line, the line should be made following the 'body-in-white' model used by car manufacturer, i.e. a fixed sequence of station where the product is assembled step by step. The 'body-in-white' model is followed by a mixed model of final assembly lines so that different seat models can be sequentially personalized on the same final assembly line.

For a manufacturing approach, three points are crucial in using a modular product architecture:

- Economies of scope: a seat-maker with a larger product range per segment will benefit from greater platform modularity;
- Economies of scale: in terms of production volumes, manufacturers with larger production in terms of the number of units manufactured per model will obtain better results on scale economies if the platform is more modular;
- Operational flexibility: this is a function of the number of plants in which it will be possible to produce the different variants based on the platform. This is not the case of Sabelt SpA because it owns only one manufacturing plant.

In order to assess the two major benefits of platform modularity, there is the need to perform an analysis about production process before and after the product platform. In this case, the analysis was conducted for the racing sector and also for OEM ones, because the product platform expands not only on racing seat but also on OEM ones. Several variables have been investigated, such as:

- Platform modularity: the number of basic independent modules making up a product;
- Product range: the number of products in the firm's portfolio or product line calculated as the average number of seat models per segment;
- Production volumes: the number of units produced during a given period, defined as the average volume of production per segment;
- Diffscope: [economies of scope of the modular platform network] – [average value for economies of scope of the standard platform networks];
- Diffscale: [economies of scale of the modular platform network] – [average value for economies of scale of the standard platform networks].

It is good to remember that economies of scope are intended, per definition, as the number of seat models produced in the manufacturing network sharing the same platform; economies of scale instead are defined as the installed production capacity in the network sharing the same platform in hundred of units per month. The table below shows the new modular product platform analysis, according to these variables:

Production line	**Platform modularity**	**Product range**	**Production volumes**	**Diffscope**	**Diffscale**
OEM before	0	14	250	0	700
OEM modular	3	16	318	2	1000
Racing before	0	3	65	0	150
Racing modular	1	4.3	93	3	230

Table 7.1: Results for adopting modular platforms

The OEM and racing production line had 0 initial modules, then turned to 1 for the racing sector (the shell) and to 2 for the OEM sector (all the electric part and then the shell with all the saddling operations) ; for the product range, with the modular platform it was possible to produce the GT-PAD in 3 different variants of color and size, adding to Taurus also the Taurus MAX (one size bigger) and to GT3 one special padding. For OEM seats, before modular platform there exist 3 different models of seat for Ferrari, 3 for McLaren and other 8 different models for respectively 5 OEM manufacturers; with the modular platform one different model for Ferrari was added - used for the 70th anniversary of the company - and one for PSA (Peugeot-Citroen group). The production volumes has been calculated in a timeframe of one month: respectively, the increase of volumes produced in one month for OEM seats was of 21% and of 30% for racing seat.
As a result, certainly, having reached a platform modularity greater than 0 means more outputs and more efficiency on economies of scope and scale. However, it is important to underline that a huge investment is needed for changing the standard production to modular one: in fact large manufacturers that have a substantial product portfolio with relatively little differentiation aim for high levels of modularity (and this is the case of Sabelt SpA but for racing seat), while companies with a smaller product range but a wider variety in size will find that their production volumes would be too small and the range of models too narrow for the development of their own modular platform to be cost-effective. The latter is the case of Sabelt SpA for OEM seats: in fact the investment needed for changing the production for only 2 models more was very huge and overwhelming for the company: in this case the solution adopted was the cooperation between the companies - Sabelt and Ferrari - aiming a developing a new modular platform, owned by Ferrari itself, but in Sabelt production plant. For racing seat instead the total investment needed consisted in a running slide able for fixing the shell and changing the saddling: the investment counted for 5000€ circa because the running slide was re-adapted from an old running slide already used for OEM production.
Strategic modularity consists in understand how the strategy of the company is been modified by the modular product introduction. Certainly, modularization can be seen as a competitive strategy that helps to respond to customers' heterogeneous demands and gain competitive advantage. Before doing this consideration, it is good to understand which is Sabelt SpA strategy before modular product introduction. Sabelt SpA is a seat and seatbelts producer and for assessing the firm's current position in the marketplace it is good to start with an external analysis, i.e. using a Porter's five-forces model. The Porter's five-forces model is illustrated in the image below:

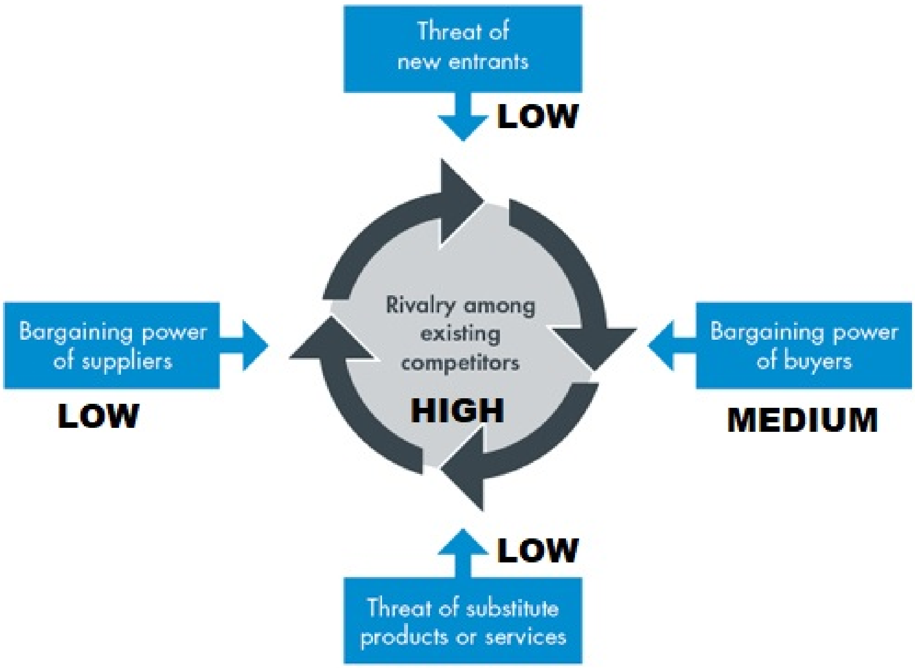


Figure 7.2: Porter's five-forces analysis

The analysis showed an high rivalry among existing firms, because all the comparable companies are of similar size and sell similar products; what differs Sabelt from other is the seatbelt category, but in this case is not the aim of this thesis.The threat of potential entrants force is low because the racing sector is really brand loyalty driven and exist high entry barriers established by governmental institution, like FIA. The bargaining power of supplier is low because there are a lot of shell and/or saddling supplier that are not highly differentiated; moreover the switching cost from one supplier to another one is minimum. The bargaining power of buyers is a medium force, because buyer could switch without any problem from one vendor to another one because the products, in general, are not highly differentiated. Finally, the threat of substitutes products is low because they are regulated by FIA norms.
The six Porter's force - the existence of complements - is very useful for Sabelt SpA strategic analysis: in fact, the highly differentiated seatbelts that Sabelt offers - they only one in zylon, a more than 40% lighter material respect to the well-known polyester ones used by all the other competitors - enhances the possibility of buying a racing seat in Sabelt respect to another competitor. From zylon discovery, in fact, in 2015, seatbelt revenues rose of 45%, gaining also the approval of 7 over 10 Formula 1 teams, and concurrently also the racing seat revenues grow of 15% respect to the previous year.
For the internal analysis, the value chain Porter's model has been applied, in order to evaluate how each activity contributes to firm value and what's firm's strength or weaknesses are in that activity.

Value chain activity	Strength	Weakness
Inbound logistic	Reliable suppliers based on decade of collaboration	
Research and Development	High R&D effort especially after 2008 crisis; established 5% of revenues for new projects every year	Well established market with few new real inventions
Operations	Sabelt focuses on less product but with higher quality, especially for seatbelt sector	
Outbound logistics		The same as other competitors; it is impossible to create a differentiation
Marketing	More social media and communication campaign, also driven by Formula 1 presence	For seats, marketing is less effective
Service	Customer support and product specialist department gives a plus to the company	
Firm infrastructure	High control systems given by ERP software and a long established company culture	
Human resource management	Hiring of highly specialized workers	Few potential workers
Procurement	Well known supplier relationship	Low bargaining power

Table 7.2: Porter's value chain internal analysis

As it can be noticed from the table and from a deeper analysis on tangible and intangible resources that lead to a competitive advantage for a firm, Sabelt SpA has a robust client base, which is an indicator of customer loyalty and company reputation. The latter are both intangible resources of the company that are valuable and are able to yield appropriable returns. If sustained efficiently, they could also be a source of long term competitive advantage. Another competitive advantage of Sabelt SpA is the long historic path-dependence knowledge about security system; for the Italian market, in fact, Sabelt was the first italian company that invested all its resources on safety belt and safety systems, even before all the italian laws of the safety were emanated (more or less in the 1984). Moreover, Sabelt SpA was the first zylon seatbelts producer, leading to have a strong connection and reliance on zylon supplier and a quasi monopolistic channel for obtaining the raw material respect to competitors. From this point of view also resources allocated to seatbelts production have a deeper knowledge about material trasformation and a long know-how on final product.
Organizational capabilities that lead to define Sabelt SpA's strategy are:

- Multidivisional coordination among different departments: in fact, several department are used to collaborate together at an high rate and they work all together in the same open - space (this lead to reorganize company layout in this last year);
- Specialized customer service: Sabelt SpA has around 95% of service level rate and one of its major characteristic is the customization features offered to potential customers both for suits and for belts.

These two organizational capabilities will lead to core competencies. A core competence, per definition, provides wide access to different market segments, makes a significant contribution to the perceived customer benefits of the end product and it is difficult for competitors to imitate because it is a complex harmonization of individual technologies and production skills. Core competences for Sabelt SpA have been identified as:

- Gaining a low-cost access to resources as a first mover for zylon;
- Long term know-how transfer about zylon manufacturing process;
- Specialized customer service;
- Multidivisional coordination among departments;,
- Historic brand reputation;
- A lot of marketing actions especially about F1 teams.

In Prahalad and Hamel's view, core competency refers to a firm's ability to use multiple resources and skills to realize some core products. Here below the graph explain Prahalad and Hamel model applied to Sabelt SpA core competencies:

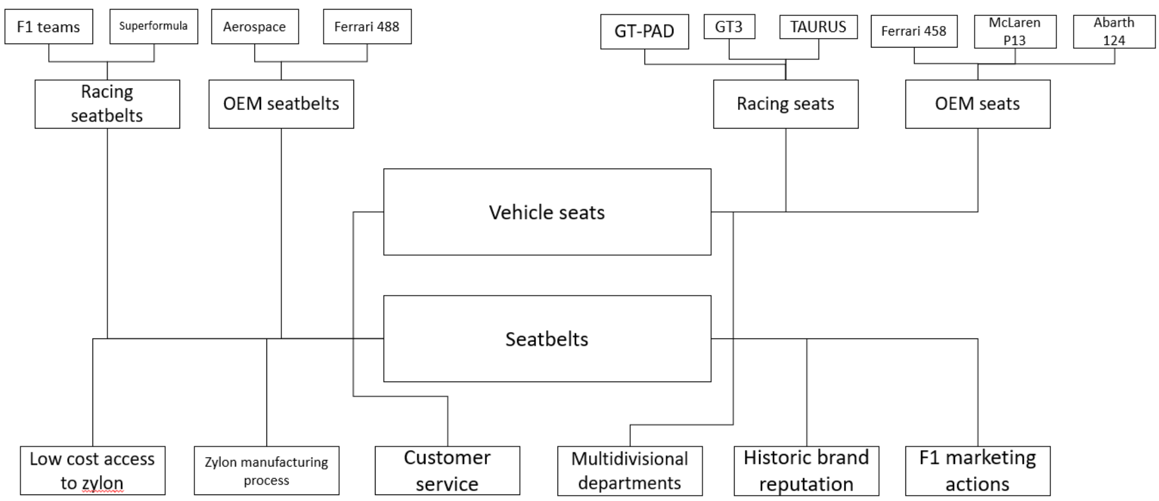


Figure 7.3: Prahalad and Hamel model

But in fast-changing markets, it can be useful for a firm to develop a core competency in responding to an extremely changing market. For this reason Sabelt decided to introduce a new modular product and decided to slightly change its strategic position, in order to quickly reconfigure its organizational structure and routines in response to new opportunities. Modular architecture product in fact reconfigured slightly the production line of seats, moving from customer oriented to product oriented configuration;

routines instead remained the same because are the most intrinsic part of the company and the most difficult to change. Modularity in production in fact creates dynamic capabilities through modular product and process architectures that integrates resources and competences in way that managers of different projects, departments, or external partners mix and match their varied skills, functional backgrounds and expertise in order to deliver revenue producing products and services.
The modular production system developed by Sabelt thanks to the development of GT-PAD gives a balance between efficiency and flexibility, adopting standardized manufacturing platforms or components that can then be mixed and matched. This gives the opportunity to achieve standardization advantages (such as efficiency and reliability) at the component level, while achieving variety and flexibility at the end product level. Because modularity enables a wider range of end configurations to be achieved from a given set of inputs, it provides a relatively cost-effective way to meet heterogeneous customer demands. Furthermore, since modularity can enable one component to be upgraded without changing other components, firms and customers are able to upgrade their products without replacing their entire system.
When products are made more modular, it enables the entire production system to be made more modular. The standard interfaces reduce the amount of coordination that must take place between the developers of different components, freeing them to pursue more flexible arrangements than the typical organizational hierarchy. For this reason, the organizational structure behind modular production is a loosely coupled organization. In a loosely coupled structure in fact, development and production activities are not tightly integrated but rather achieve coordination through their adherence to shared objectives and common standards. In this way less need for integration frees firms to pursue more flexible research and development and production configurations; moreover, the firm can become more specialized by focusing on a few key aspects of technological innovation that relate closely to the firm's core competencies: in Sabelt's case in fact, the development of a unique production platform for three different seat models enables the firm to transfer two resources from seat production to zylon seatbelt production, leading to an increase in production of 15% in terms of number of seatbelt produced. Focusing on those activities in which the firm has a competitive advantage, the firm can improve its chance of developing a product that has a price-to-value ratio that attracts customers while reducing the overhead and administrative complexity of maintaining a wide scope of activities.
In general, the strategy used by Sabelt SpA has a benefit differentiation logic, expressed through benefit superiority. The products offered in fact have much higher quality (= higher benefits) at higher cost than rivals (and so consequently higher price). It's good to remember that benefit differentiation strategy is effective for Sabelt because the company exploits yet economies of learning and scale and, most of all, the products sold are experience goods and the reputation of the company impacts a lot on customer choices.

Chapter 8

Conclusions

In conclusion, the aim of this thesis was to completely follow the New Product Development process for developing the first modular product in the product range of Sabelt SpA. Moreover, several considerations about company strategy has been done and some changes, after modular product development, have been introduced:

- A new platform for seat production has been implemented, leading to increase the number of seat models and the efficiency of production line;
- A change in production organizational structure, moving two resources from seat to seatbelt production, leveraging in this way more on Sabelt competitive advantage;
- Introduction of modularity during design phase and speed up of design and production phases, that now could overlap;
- Possibility of customization and made-to-order products, adding variety and flexibility at the end product level.

All this things are completely new for the company that now is still working for implementing them.
Future developments consist in implementing the modular seat platform, for organizing in a better way production layout and trying to pursuing in a very pressing way the benefit differentiation strategy already adopted by Sabelt SpA.

Glossary

ABC Activity-Based Cost 34

BoM Bill of Material 42

ECV Expected Commercial Value 15, 17

EOQ Economic Order Quantity 69

FA Factor Analysis 22

FAST Function Analysis System Technique 43

FIA Federacion International de l'Automobile 55

IRI Innovation Research Interchange 9

MFD Modular Function Deployment 49

MIM Module Indication Matrix 49, 50

MIP Modularity In Production 72

NPD New Product Development 9, 19

NPV Net Present Value 15

PCA Principal Component Analysis 22

PPM Project Portfolio Management 12

PRI Performance Racing Industry 20

PT Payback Time 15

QFD Quality Function Deployment 20, 31

RBV Resource Based View 10

RTM Resin Transfer Moulding 67

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