Automotive, experimental car, innovation techniques integration, innovation tools, product design, prototyping.

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PRODUCT DESIGN TECHNIQUES IN AUTOMOTIVE PRODUCTION

Abstract

In the present and medium term perspective in the future, the mechanical engineering and other industrial branches are facing advanced challenges arising from global changes in the technical, economic and social environment. Submitted article deals with the approach to Product design in automotive sector that is using benefits from the synergic effect of utilizing the innovative methods, techniques and tools, within the integrated model of complex product development. The suggested paradigm is demonstrated on the project of experimental car ICAR 2010 at the Faculty of Mechanical Engineering, Technical University of Kosice, Slovakia.

1. INTRODUCTION

The automotive sector is facing advanced challenges arising from global changes in the technical, economic and social environment. Trend, referred to as the "agile manufacturing" represents the ability to survive and prosper in a competitive environment of continuous and unpredictable changes. It means to respond quickly and effectively to changing markets, produce goods and services according to customer needs via maintain the continuous product innovation, manageable number of product variants, fulfilling the unpredictable requirements of customers, shortening product life cycle and respond to significant fluctuations in sales.

Agile production is different from the lean in the sense that lean production is oriented on the repetitive manufacturing environment with focus on high-volume and low mix, since the agile production is applicable to low-volume and high mix. It is suited to an environment where configurable or specialized products offer a competitive advantage [1].

In the present and medium term perspective in the future, the mechanical engineering and other industrial branches are facing advanced challenges arising from global changes in the technical, economic and social environment. They are influenced by the previous financial

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crisis, followed by the debt crisis (pressure to reduce costs, entering the new markets, innovation and so on).

2. INNOVATION MODEL FOR THE SOLUTION

In important part of the preparatory phase of the project is the analysis of innovation models and selection of the preferred model. Models of innovation inherently respond to changes in the innovation environment, so there are many different models. Basically, there can be distinguished 2 main groups and 5 basic generations of models, as follows [2]:

Traditional linear models of innovation:

- Push model: Science initiates innovation (new knowledge – innovative design – production – customer)
- Pull model: Demands of potential customers – innovation comes from the unmet needs of customers (customers – innovative design – production)

Interactive models: Combination of push of science and pull of customer demands through the feedback loop. Research, development and marketing are in balance.

- Coupling model: interactions between the different elements and feedback between them
- Parallel model: integration between the companies, linking with key suppliers and active customers, emphasis on bindings and alliances, system integration, large networks, flexible and tailored response to continuous innovation.
- Network model: system integration, wide networks, flexible and tailored reactions of radical innovations.

The transformation from traditional, closed innovation to modern, open and performed within the network, is not without problems. Trend is to work also with partners with not clearly and poorly structured problems related to innovation, comprehensive thinking on innovation with a strong focus on future developments and the possible needs of potential users. The challenging tasks of design of innovation processes in the network are:

- Knowledge of integration across the organizations
- Format of partnership for innovation in the network
- Identification of strategic partners
- Balancing the goals and future vision for innovation in the network
- Team structures for innovation in the network
- Skills and practices for innovation networks
- Model for network innovation

3. INNOVATION TECHNIQUES AND TOOLS INTEGRATION APPROACH FOR AN EFFECTIVE PRODUCT DESIGN

Experience from development projects proved that for innovation process in the field of automotive components is the integrated portfolio of innovation methods and techniques an excellent way to gain the benefits of lean approach. The recipe for successful portfolio mixture must consist of four essential ingredients:

3.1. Analytic innovation methods and techniques

They are intended for gathering and evaluation of source data for innovation process and its particular phases launch, including i.a.:

- **Surveys:** marketing surveys for future product users, surveys for branch experts, etc. As a tool of open and user innovation they are helping to refine the product innovation according to user needs and demands. In combination with taking the opinions or suggestions branch specialists into account provide the unique tool to adjust the product bespoke target user groups and assure the competitive success.
- **Benchmarking** of competitive products. Helps development teams become familiar with the bill of materials, part count, features etc. of competitive products in the appropriate segments in order to understand how to improve the engineering and/or design of the product and trends in the area. The more complex, detailed and numerous (in terms of examined competitive products) the benchmarking is, the better. There is also recommended to perform the examination outside the product segment's boundaries, in order to explore and identify key differentiating features as the optional areas for improvements.
- **Innovation intelligence** focused on inspiration suggestions (product architecture, new functions, materials, technologies, fields of application, etc.) partially utilizes benchmarking results, which, combined with new knowledge can be the source of new innovation ideas.

3.2. Creative methods and techniques

In the beginning of the innovation process are used to generating innovation ideas, their evaluation and transformation to innovation opportunities, and also in concept creation. Some of them play in the next phases the role of stimulating pulses for subsequent appropriate outputs routine. Here belongs a number of methods and techniques, i.a.:

- **Brainstorming (brainwriting).** Spontaneous and quick random generating of number of ideas can be useful for almost each problem solving. For example, within the many projects were solved the questions of conceptual frame, original shape design, etc. this way.
- **TRIZ.** Uses algorithmic approach (unlike random in brainstorming) to solve the contradictions using the typical solutions where the ideal final result is predetermined (set within the statement of work - SOW, according to customer standards, legal regulations etc.). Within the project development can TRIZ be used to solve the contradictions in interfaces between existing platform and new shapes, where particular elements are defined by customer as not changeable.
- **Morphologic tables / morphologic map.** As illustrated on figure 1 in an example of automotive seat development, this tool is intended to quick design alternatives creation. It has shown very useful by generating headrest, lumbar bolster shape, and additional features.

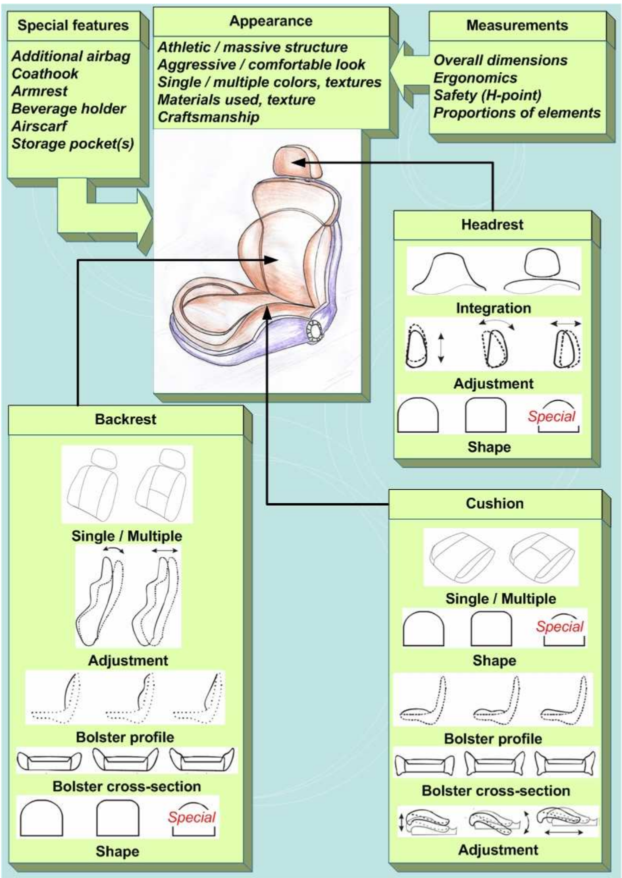

Fig. 1. Morphologic map - example

3.3. Control and testing methods and techniques

Their role is to reveal risks and possible weaknesses of actual state before and during the phases of innovation process help to eliminate them, and provide the boundaries of the acceptable innovation. For example:

- **Quality function deployment (QFD)** is an extremely powerful catalyst for driving in quality at all stages of the product life cycle. It integrates quality throughout the value chain by starting with the Voice of Customer (VOC) and working with quality until the positive impact on customer satisfaction is achieved. The VOC (customers' requirements as expressed in their own terms) is translated into final product characteristics expressed in technical terms with help of the series of matrices.
- **Failure mode and effect analysis (FMEA)** reveals the potential weaknesses of the analyzed system and suggest the recommended actions towards the critical and significant characteristics**.** The Design FMEA (DFMEA) in product design must primarily take into account following groups of product functions (ordered by descending importance): legal (legislation and standards), safety, operational (basic

functionality), comfort of use, manufacturing and assembly feasibility, ergonomics, robustness (reliability and durability), and haptic and optic functions.

- **Cause – effect diagram** is the fishbone shape diagram heading to negative state and describing the groups of negative factors leading to the negative state. The more clearly and accurate reason is defined, the best chance is to eliminate it fast and cheap.
- **Design to cost (DTC), Design for manufacturing/assembly (DFM/A), etc.** are so called "design for X" methodologies, where X may correspond to one of dozens of quality criteria such as reliability, serviceability, environmental impact, manufacturability, etc., or particular costs within specified boundaries. Basic general principles for achieving any of the Xs in DFX are: detail design decisions can have substantial impact on product quality and cost; development teams face multiple, and often conflicting, goals; it is important to have metrics with which to compare alternative designs; dramatic improvements often require substantial creative efforts early in the process. A well defined method assists the decision-making process.
- **SWOT analysis** despite the lack of measurement accuracy, it can be very useful e.g. for technical meetings for brief description of actual results.

3.4. Support techniques and tools

- **CA technologies** accelerate, simplify, and enhance quality of outputs of routine procedures, and allow limited testing via simulations.
- **Integrated cycle of shape design refinement:** Optimization – Model fabrication, prototyping – Reverse engineering. As soon as the geometry is defined, the physical model can be built as a first visualization. There are a number of methods and techniques available to make a mock-up, e.g. clay modelling, foam blocks hand tooling, epoxy resin laminating, silicone moulding and urethane casting etc. For the further development of the car, the CAD model is needed. To get a CAD model, the reverse engineering phase has to be performed. This involves the preparation of the model (fixing the mock-up and the definition of the reference points in order to stitching the surfaces correctly), digitizing (obtaining the point cloud) and final corrections and conversion (smoothing and stitching the surfaces and export to the interchangeable CAD file format).
- **Rapid prototyping** means not only use of computer-aided manufacturing (whether CNC machining or layered manufacturing), but the quickest and cheapest way of fabrication of prototypes (or mock-ups) with optimum quality, which means to sufficiently fulfil the needs in current state of product development. In addition to conventional technologies and materials, the use of easy formable materials (polyurethane or polystyrene foams and blocks) makes good.
- **Network-based development** represents one of the paradigms of innovative approaches to product development in cooperation with various partners within the network. Selected of involved partners are engaged in the individual phases and there are created virtual sub-teams ad hoc in order to create outputs needed (concept frame, QFD, benchmarking, FMEA, analyses, surveys, documentation, optimizing, etc.). General paradigm of such as network for product design is shown on figure 1. Advantage of this approach is lean and flexible team with clearly defined competences and responsibility of each team member. Result is the save of time since

every member takes part only on assigned work tasks. Thanks to IT support is each involved partner informed about current progress of single tasks, which can comment, or consult the correspondence with own task results and further proceedings. Combined with parallel solving of several partial tasks is there applying the simultaneous engineering approach that brings saves of time and costs, and brings competitive advantage in terms of advanced design robustness.

- **E-community**. According to purpose of the community and structure of the team, the specific needs and requirements, as good as the levels of utilization of the specific tools often vary. The reasons are various: sometimes are the skills of the team members insufficient to use some of the tools, the nature of the project may not allow using them or it will only complicate the work, or the specific tool may be too simple to support the solution of advanced tasks or it doesn't provide the results as it is required and needed. That's why the crucial role of the community manager (project team leader), in addition to planning, scheduling and coordinating the community activities and motivating the team members, is to adjust the environment and available tools to gain an optimum profitability. The software support of e-community can be also various according to the conditions mentioned above. The highest and most complex level of integration of these tools is within the frame of so called CMSs (Content management systems).

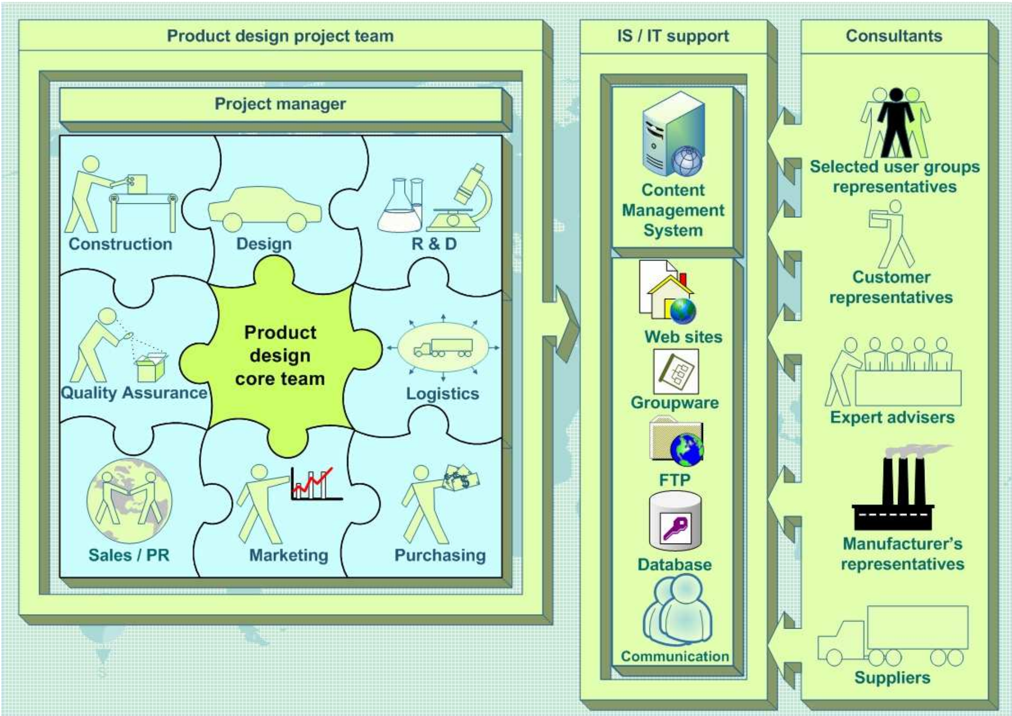

Fig. 2. General paradigm of a network for product design

4. PRODUCT DESIGN CASE STUDY: COMPLEX PRODUCT – EXPERIMENTAL CAR ICAR 2010

The main goal of the development of experimental vehicle ICAR 2010 was to design and realize a functional prototype of a sports car for leisure. Within the frame of the project were involved student teams under the leadership of assistants and researchers of the Department of technology and materials and Innovation centre of automotive production at Faculty of Mechanical Engineering, Technical university of Kosice., automotive and department of innovation centers. The statement of work for team tasks contained well-defined procedures for the development. Among the car body components under the development were e.g. front and rear hood, bumpers, fenders and car skeleton. There have also been proposals for the interior, which got a corresponding new look in order to match the new look of the exterior. Adjustments did also not avoid the vehicle chassis and engine with the exhaust system, which was completely rebuilt. The whole project was based on the chassis and basis of the body frame of Skoda Fabia 1.9 TDi, production year 2001 (Fig. 3). Since it was a prototype vehicle, the body was made of fiberglass and composite materials, followed by surface coating in order to gain the ultimate visual experience.

Fig. 3. Škoda Fabia 1.9 TDi, production year 2001

4.1. Philosophy, design and development process

In the beginning of the development of concept were clarified certain ideas to project kick-off. The car should have sporty roadster look with dynamic features, aggressive grillee and also should excel in elegance that would have taken every sports car enthusiast. Pilot task in project management was to divide the different roles, responsibilities and hierarchical positions of the development core team. The production itself was preceded by a series of developmental preparation with concept design frame of the overall shape of the car. An analysis of competing solutions from different designers from around the world brought to the process of design an inspiration that led to the exact specifications of the design boundaries. It was important vehicle to maintain the linear structure of the two-seat roadster, obviously with regard to performance, safety and future operation of the car. There was crucial to keep these features within the boundaries of limited resources (budget and available means of production – tools, technologies, etc.).

The core team in this phase consisted of 6 members. The initial brainstorming included the assignment of responsibilities for certain project parts / car components of each team member. The car body as a system was divided into separate parts (front, rear, doors), each part was assigned to two team members.

The specific parts were solved individually in a number of variants. The solutions were subsequently integrated using the technique of morphology. By eliminating the unsatisfactory combination was refined the conceptual overall look of the vehicle. After the evaluation and assessment of the proposals was approved the final design as the basis for start-up of the prototype fabrication. An important part of this project phase was the choice of material and technologies. Based on the selection of appropriate solution was realized the manufacturing process of body construction. There were defined enhanced teams with identification of positions in the workplace and set the production schedule. The precise scheduling of work was an important part of production in order to coordinate the specific activities. In the case, when delay in specified deadlines occurred, was necessary to find the cause and subsequent solution and further prevention of the problem. It was also necessary to ensure logistic flow of material for the production of components and functional units.

Technical preparation of manufacturing included set of technical, technological, organizational and economic measures, intended to gain the excellent technical level of the results, streamline the organization of the prototype fabrication, optimal economic results, and to keep the scheduling of manufacturing of required components just in time. Before the manufacturing kick-off were set the control milestones. A failure to meet these deadlines would result in a problem, so in such cases the root cause had to be detected and the appropriate measures were taken. This way, the student teams were able to verify the functionality of the system in real conditions and on real product. If any conflict situation, or a variety of issues related to realization of such an extensive project occurred, each team member was able to directly intervene in the manufacturing process and thus affect the outcome of both his own work and the work of the whole team, or even other teams on the other hand.

The next step was the distribution of labor in the workplace individually for each member of each team. Finally, it was necessary to ensure the logistics of manufacturing that included the continuous supply of material to prevent the waste of time and ensure the continuous workflow. It should be appreciated the cooperation of the management of the Faculty of Mechanical Engineering, under auspices of which was this project realized. The project was financed solely by the faculty, without any sponsorship donations, since it was an effort to gain the clean, independent design and realization without the external interventions, as the original work of students and staff of the Department of Technology and Materials and Innovation center of automotive production.

Characteristics of the experimental vehicle

- As the platform was chosen Škoda Fabia,
- Designed and manufactured new styling of car body and interior,
- Duration of preparatory activities, concept creation a technology preparation: 1 school year,
- Duration of manufacturing: 1 school year,
- Materials used: glass and carbon fiber laminates, urethane foam, polystyrene foam.

Specific features

- Type: two-seat roadster,
- Original car body with wing doors, built-in steel reinforcements, laminated body parts – glass fiber and carbon fiber,
- Original interior,
- Enhanced engine power.

Technical parameters

Tab.1: Technical parameters

Length/width/height [mm]	**4180/1700/1395**
Wheelbase axle [mm]	2462
Track width front/rear [mm]	1485/1475
Cylindres/valves/fuel	4/8/D
Engine displacement [cm^3]	1896
Engine power [kW/HP]	88/120

5. LAYOUT, PRODUCTION AND FINAL VERSION OF ICAR

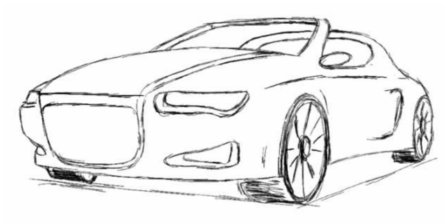

Fig. 4. Initial sketching

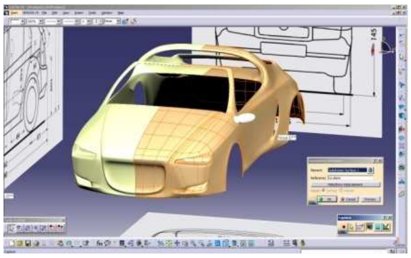

Fig. 5. CAD modelling (CATIA)

Fig. 6. Final CAD model

Fig. 7. Mockup fabrication (scale 1:4)

Fig. 8. Platform preparation


Fig. 9. Model fabrication and preparation of laminating molds (scale 1:1)


Fig. 10. Dashboard fabrication


Fig. 11. Dashboard – final look


Fig. 12. Interior ergonomy evaluation


Fig. 13. Finished vehicle – front view

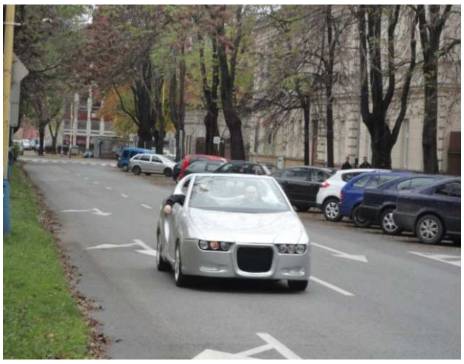
Fig. 14. Driving tests

Fig. 15. Core development team

6. PRODUCT DESIGN CASE STUDY: COMPONENT – FRONT BUMPER DESIGN FOR ICAR 2010

6.1. Design development process

After defining the basic requirements (mission statement) were generated various proposals and visualized in the form of sketches. It was crucial to take into account the default dimensions of the body and individual body elements of the Skoda Fabia. It has to be avoided excessive expansion or contraction of the component. To ensure the overall concept of the car, it was necessary to decide on the overall appearance using the pre-drawn quick proposals. Final selection was based on the evaluation of three proposals that were shortlisted from number of the original proposals. Crucial criteria were to reflect the overall shape, which had to correspond with the rest of the body and form optically one whole, and of course, to take into account the functionality of the various elements that had to be implemented in the area of the front bumper. The proposals selected for complete evaluation already included slight differences, but also gave more space for corrections in the draft.

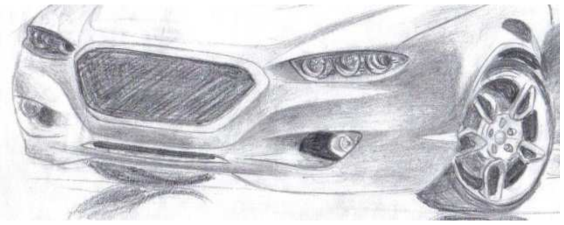

Fig. 16. Quick design proposal No. 1

In this phase, the bumper has been appropriately adapted to hood and fenders. The hood should be characterized by a slight curve, which smoothly passes through to the bumper (Fig. 16). At the bottom of the bumper on both sides were strong lines that extended the spoiler. At the bottom sides, the bumper passed in the middle up from bottom, making the impression of spoiler. There were anticipated the large holes for fog lights.

Fig. 17. Quick design proposal No. 2

Other proposal for the evaluation presented a significant and massive bumper with a massive grille (Fig. 17). This proposal required the shortened hood, thus the front bumper continuously run into it. Lights in the proposal were embedded inside, and therefore the forehead of the bumper on both sides turned toward the grille. Fog lights were outlined in a narrow hole at the bottom.

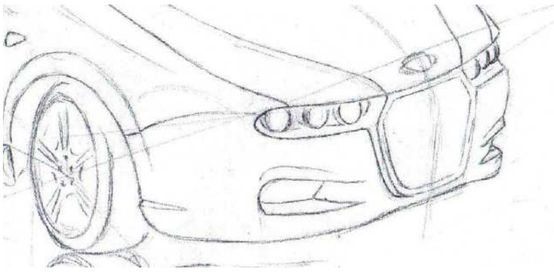

Fig. 18. Quick design proposal No. 3

Using the gallery tool combined with concept testing and evaluation tools mentioned above, was decided that the ultimate final proposal suitable for elaboration and realization will be design solution, as shown in Fig. 18. As shown, this proposal has a smooth shape of the front bumper. Its clearance is based on the original design, the bumper outer curve continues fluently through the fender area to lamp holes, where it allows setting off the hood. Headlamps are slightly vanishing into the bumper holes and slightly hidden under the bonnet. The curves of the bonnet continuously disappear in curves of the grille, which has a symmetrical shape. Conspicuous are also the holes for fog lights that are embedded and vanish in the bumper in the middle of its cross-section.

Based on the selection of appropriate proposal, the next phase was the manufacturing of the bumper. Team members were delegated with the work positions, competencies and the responsibilities within the prototyping process and the work schedule was set. The schedule was integrated into the main overall schedule in order to coordinate with design and manufacturing processes of other parts.

6.2. Manufacturing

Manufacturing of the front bumper consisted of several stages. The first is phase was the preparation of the polystyrene model, a template, as the basis for the next stage of prototyping. There was used the polystyrene block (Fig. 19) created from polystyrene plates glued together. The glued block had to cure until the next day to gain the optimal quality for further treatment of the material. Subsequently, the desired shape outline of the bumper was drawn on the material block.

Fig. 19. Initial shape of the polystyrene block, prepared for further processing

Next phase included the cutting of the rough shape of the bumper using the resistance wire. The rough shape had to keep the machining allowance of about 20 mm. Next phase was to refine the rough shape and create the basic features - front mask, grille opening, and suction and lamp holes.

The next task was to solve the mounting of the bumper on the car body. It was necessary to propose mounting elements and whole construction to ensure rigidity and stiffness of the cross girder and assembly node on the bumper brackets. The stiffness of the bracket was ensured by designing the supporting structure with dilatation girders.

In the next phase was realized a number of adjustments to balance the trade-offs between initial concept design and issues from prototyping (design for manufacturing/assembly optimization) to get the final design of the bumper. As shown in the figure (Fig. 20), there was adjusted the side length, car was optically lowered by reducing the gap between fender arches and wheel, and the bottom section has been sunk inwards to set off the contrast and thus enhance the aggressive sports look of the vehicle.

Fig. 20. Prototype of the bumper before (left) and after the adjustments

The most difficult part of the process was the final phase of this stage; here was a crucial issue of the trade-offs between the surrounding components had to be solved. There is an area, where hood, fender, and bumper join together. Another critical part was to balance the shape of bonnet with bumper and headlamp holes. Moreover, there was necessary to adjust the fog light holes, curved at the ends to semicircle to receive a follow-up to the curve shape. All these issues had to be solved in unified procedures, the same way, what required more effort to manage and coordinate.

In the end of this phase was the polystyrene model of the bumper adjusted to its final shape and thus was ready for the final stage of its manufacturing (Fig. 21). After applying the basic coating color was model finished and ready for use as a mold for laminating, using the epoxy resin and glass or carbon fiber.

Fig. 21. Finished polystyrene model of the bumper

7. CONCLUSION

There is a growth in the need for products with higher added value, based on new knowledge implemented from research. It seems to be the only way to compete with the mass production of low-cost countries and changes in the field of technology. Lots of renowned analyses worldwide indicate that currently there is a technological turning point, which is e.g. in the automotive industry the biggest over the past 50 years. To adapt quickly to changing market conditions is in this case “sine qua non”. For companies, this means maintain the continuous product innovation, manageable number of product variants, fulfilling the unpredictable requirements of customers, shortening product life cycle and respond to significant fluctuations in sales.

The driving forces behind the network innovations are growing difficulties to maintain competitiveness in the field of technology and product development. Product life cycles are becoming shorter due to rapid technological developments and change of customer preferences. At the same time, the cost of R & D and technical requirements for new products are increasing, the availability of talented workers is decreasing and the degree of specialization increases. These three forces increase the pressure on the efficiency of research and development.

As shown in the case studies, in the beginning of the development of concept are certain ideas to be clarified before the project kick-off. The more specific is the initial vision of the project proceedings, the less space it remains for creativity, and vice versa, so it is crucial tofind the just right balance for each project. Pilot task in project management is to divide the different roles, responsibilities and hierarchical positions of the development core team and maintain an open and communicative atmosphere, leading to quick and satisfactory solutions of various issues. Project realization must be preceded by a series of developmental preparation with concept design frame. An analysis of competing solutions from different external and internal resources around the world brings to the process of design an inspiration that lead to the exact (or well refined, at least) specifications of the design boundaries. It is necessary prerequisite to elaborate a file of evaluation criteria that help to keep the project within the boundaries and gain the intended goals.

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