SIMULATION CHALLENGES IN THE DEVELOPMENT PROCESS OF A COMPLEX PRODUCT: DESIGN OF VIRTUAL ELECTRIC SPORTS CAR

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ABSTRACT

The project being introduced is a simulation of an industrial Product Development project as a large scale student project in a university setting. The scientific goal with the project is to develop and test different management, design and engineering simulations, the practical goal however is to provide a real-like project environment for the students, which fit to academic conditions most perfectly. The target of the development process is to design a fully electric sports car. The outcome of the project would be a detailed Digital Mock-Up, on which Virtual Simulations will be carried out. In the paper the background necessary for establishing the process simulation will be presented, besides the successful realization will be proven by showing the recent achievements from the project. The Digital Mock-Up is being developed by applying the Concurrent Engineering approach, the development process is closely supported by project management activities. The necessary virtual test will be carried out by university students on the specific parts of the sports car following the protocols being used in industry. The realization of a simulation project of such a complexity provides great opportunity for both students and teachers/researchers to gain invaluable knowledge and scientifically relevant findings.

INTRODUCTION

It is above all dispute that the role of highly detailed Virtual Simulation (VS) methods and tools in the Product Development (PD) process is important in industrial environment. Companies face increasing number and increasing complexity of challenges throughout the development process. Products reach higher and higher complexity and in parallel the time to market period decreases very fast (Becker et al. 2005). With the application of VS companies handle those two factors reasonably well. VS models and tests the behaviour of the product or a component from a specific perspective by simulating realistic environment, therefore enables companies to reduce design time and design risks. The rapid development of Information Technologies (IT) continuously provides new opportunities for emergent and developing VS applications ranging from different Finite Element Analyses (FEA) to maintenance simulation (Alabdulkarim 2011).

Nowadays no company could introduce a competitive product without the utilization of upper mentioned virtual technologies; and the same rule applies to Higher Education (HE) as well. However, universities do not produce competitive products but disseminate competitive knowledge to foster the creation of competitive products. This paper will focus on technical HE, with a closer look on the field of engineering design. Engineering design students have to have up-to-date knowledge in their specialization, which is impossible to get acquired without getting familiar with the latest VS technologies. To achieve this goal, HE institutions may have two options.

Many universities in Hungarian HE have the opportunity to collaborate with industrial companies in industry-academia PD projects. In this frame students meet the industrial procedures and protocols and work as ‘subcontractors’ in a project. This type of collaboration is not uncommon, however it has its pitfalls, e.g. the mismatch between the company and the university expectations, the different time-frames and time-scales of the project and the academic calendar, etc. The major characteristic of an industry-academia project is that the design assignment, most of the input requirements and specifications come from the company side, and the project manager is at the company, too. While the decisions are mainly made inside the company, the project management workload is on the HE institution. A generic model of a VS oriented PD process is shown on Figure 1.

For this reason it is assumed that the simulation of industrial PD processes within the frame of educational projects would fit the HE institutes’ goals and resources better. This kind of complex VS was missing from the palette of the Hungarian HE, so the initial idea was to establish a *virtual simulation of an industrial project*. This was meant to model all the main characteristics of

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an industrial PD process in one single educational industry-independent academic project, which literally meant to exclude any company involvement on the input side.

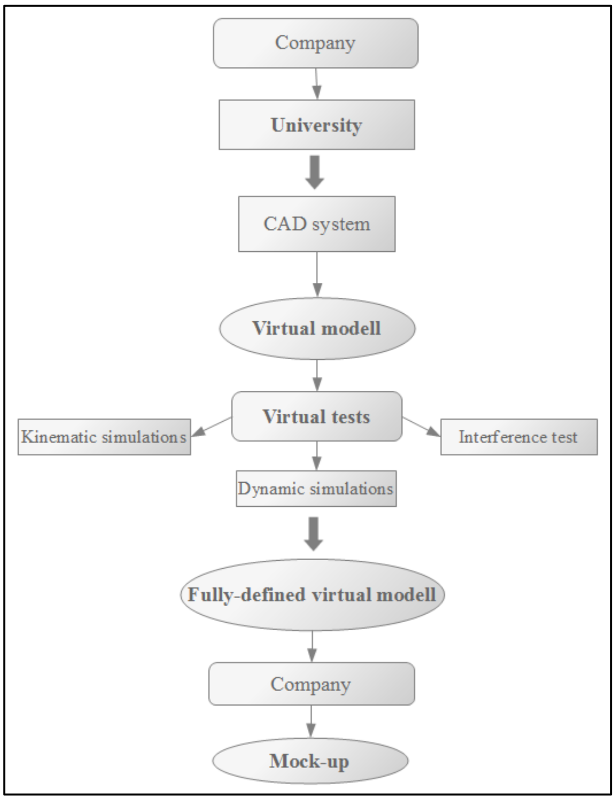

Figure 1: The Generic Model of a VS oriented PD Process in HE Environment

MOTIVATION AND CHALLENGES

The goal of the VS in question is to create a complex virtual product, the output from the PD process will be a Digital Mock-Up (DMU). This DMU is being created according to the Concurrent Engineering (CE) philosophy. CE is a commonly accepted design method in industry for decreasing the time to market of a product (Clark and Fujimoto 1991). The VS is being continuously supported by a variety of project management tools. These tools ease the handling of complex, multi-participant design projects (Cho and Eppinger 2005).

Planning and scheduling of the PD process is always hard because the output and the run-off paths are affected by numerous factors and therefore the risks are high (Szélig et al. 2011). The biggest challenge for the teachers involved in the project is the set-up of the theoretical and technical background for the simulation of the industrial PD process. Teachers have to model the project run-off in advance and identify the possible risks, which calls for the application of different project management tools at the teachers' side. Parallel to that, the technical background of the VS must be set up by installing a database providing access for all participants of the project. Students also need support in terms of software access and usage for the successful execution of the VSs. On Figure 2 the overall simulation environment of the project is presented.

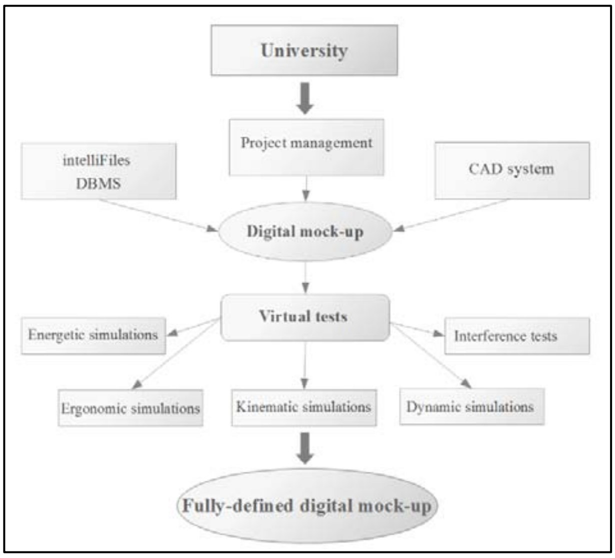

Figure 2: The Simulation Environment of the Project

This kind of design project is fruitful for both students and teachers. Students can extend their theoretical knowledge and apply it by participating in a project simulating a real one. Students become experienced with the work-flow where a number of engineers work on the same product in parallel, and where also the boundaries and the parameters are either pre-determined or related. The DMU provides a good opportunity for trying out the acquired knowledge on the VSs.

As it was described earlier, exclusively university students are involved in this project. Due to the complexity and cross-disciplinary character of the project, dynamic multi-disciplinary student teams were formed, where students with different specializations (engineering design, mechatronics, industrial design engineering, management studies) are working together. It is a highlighted aim in the future to involve the most students from different fields, which is made possible by the virtual characteristic of the project. The set-up of the students involved is illustrated on Figure 3. The teams are changing continuously and flexibly according to the project needs: as the different sub-systems are being developed or as more specific knowledge is necessary, etc.

Number of students	Mechanical Engineer	Industrial Design Engineer	Mechatronics Engineer	Engineering Manager
2013 I.semester	2	-	-	-
2013 summer	4	-	2	-
2013 II. semester	4	1	1	1
2014 I. semester	2	1	-	-

Figure 3: The Mix of Students by Specialization

The introduction of this PD simulation project into education means new challenges to the university and also provides invaluable experiences to the students. This kind of complex VS also has high scientific potential. The next section introduces the VS more in details.

THE OVERVIEW OF THE PROJECT

The subject of the simulation of the PD process is fully electric driven virtual sports car (Figure 4). For the first sight the fully electric propelled vehicle looks highly innovative but the idea itself dates back long in the history. The first fully electric vehicle was created by French G. Trouvé in 1881, four years before Carl Benz was to demonstrate the first operating internal combustion engine vehicle (both were tricycles) (Westbrook 2001). Nowadays the pure electric drive comes to the front again thanks to the increasing weights of the environmental aspects. It is common sense, local pollution is not emitted by solely electric driven vehicles. Furthermore – in comparison –, the drive-train of the electric sports car is much simpler than the drive-train of an internal combustion car, for e.g. it requires less moving parts and auxiliary components.

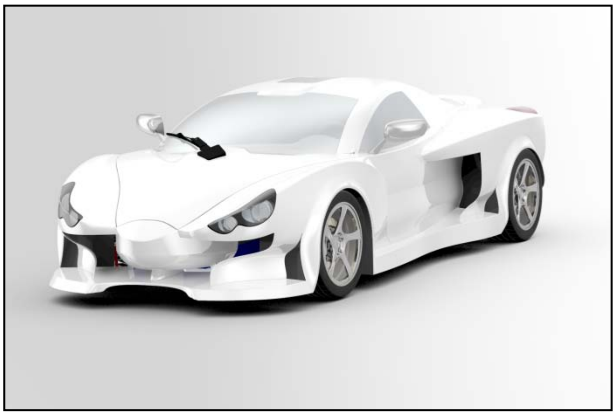

Figure 4: The Electric-Driven Sports Car

A uniquely electric powered vehicle has its weak points as well. Most of the difficulties are caused by the batteries because due to their size and weight, although this is the most intensive area of research. Currently the commercial battery technology and infrastructure are ‘half-baked’; in practice, a short range of distance and on top of that, rare charging stations and long recharge times limit the usage against the internal combustion (and hybrid) technology.

Independently of these disadvantages electric vehicles have great perspective, so leading car manufacturers cannot afford to ignore this type of cars. This area is interesting and – what is more important – really a rewarding area for HE and research institutions. These reasons lead us to choose this subject for the VS project.

Input Parameters

The car design has many fixed parameters and boundary conditions. As a first step, the two most influencing design tasks, namely the conceptual design of the drive-train and the car exterior design have been completed by two students in their major thesis works. This can be considered as the preliminary design of the vehicle, which then provided the basis for designing the upcoming sub-systems.

At the beginning of the project the following initial parameters have been defined. The car is a two-seater and can transport a driver and one passenger. The sporty style of the car suggests a racing application but this car is intended to be a typical second car of the family complying with the rules of the road. The core of the chassis is a carbon monocoque cell extended with two auxiliary aluminium frames. Similarly to the monocoque body the material of the outer shell is also carbon composite. The driving power is provided by two YASA 400 electric motors, each 400 Nm of maximum output torque, independently built in the rear. There are two mechanical gearboxes attached to the electric motors. The 200 km range with an average speed of 150 km/h with a single recharge was an also important initial condition. Lithium-Polymer batteries with 85 kWh capacity was chosen to meet the previous requirement. The next chapter describes the realization of this project.

SIMULATION OF INDUSTRIAL ENVIRONMENT

A project with such a high complexity and long duration requires special preparation before its start. On the one hand those are related to project planning, on the other hand those are concerning to the technical background.

Scheduling

The scheduling of the design process needs careful preparation. The final success of the project is significantly influenced by the proper planning of these design steps.
Since the PD is simulated as a project the preparations regarding the work-flow was the project management is based on traditional methods. After the specification of the project goal the network diagram was developed. The first step was to analyze the system of the sports car and to identify the design tasks in order to create the Work Breakdown Structure WBS) (Haugan 2001). A network based technique was applied to schedule the project. The Critical Path Method (Kelley and Walker 1959) was combined with the PERT evaluation (Fazar 1959) The traditional time estimation was replaced with a fuzzy based evaluation method (Piros and Veres 2013) in the scheduling procedure. Based on these techniques the whole project network diagram was created including the Critical Path (CP) (Figure 5).

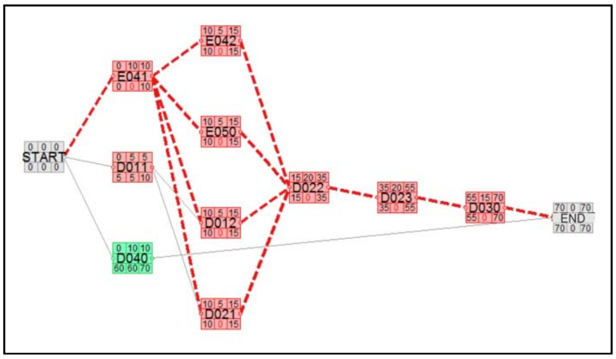

Figure 5: The PERT Network Diagram with the CP

Resources (students working in semester projects, major and final projects, etc.) then could be allocated to the project accordingly, and the participating students are possible to be monitored to collect continuous and accurate feedback about the status of the project. This data is post-processed for further research purposes to assist in the development of a new mathematical model to model and estimate risk of design processes.

Design Approach

During the preparatory phase of the project the formation of the technical background plays just as important role as project scheduling. The first step in the realization of the virtual model of the sports car was the creation of the product structure which guarantees the proper location of each component in such a complex system. During the realization of the product structure the selected design philosophy must be taken into consideration. This selected design approach was the Top-Down Design (TDD) approach which comes with many advantages. The TDD method controls the whole design procedure from the top level of the design structure, and suits well to the custom-designed systems. When applying the TDD the controlling element is the overall concept called the design skeleton, which is the basis of the whole virtual model. The model structure is broken down into sub-assemblies then the individual components are being designed according to the concept. The TDD approach generally requires a low amount of input information, and all modifications are initiated on the conceptual level. This method fits well to CE providing the opportunity to design the different sub-assemblies in parallel (Misra 2008). In the meantime, in line with the definition of the product structure the creation of the related data structure is also required according to the hierarchy levels of the system to be able to manage and store the files of the assemblies, sub-assemblies and individual components. In order to achieve this a novel generic identification system was developed which is assumed to be applicable in future projects as well.

IT Support

Once the model structure is ready the concepts on the specific assembly levels could be developed, which obviously require a 3D CAD system. Budapest University of Technology and Economy (BME) is in the lucky position to have access to many makes of CAD software and maintain good relationship with the resellers. Thanks to that the project is supplied with educational software licenses. As the main computer support tool in the design process the monolithic PTC Creo 2.0 CAD environment is being used by the participants. This CAD system is widely used in industry, and has all the required features to realize the DMU and has sufficient modules to execute the different VSs.

In the case of complex technical projects, where numerous engineers collaborate the application of a Product Data Management (PDM) system is of essential importance. The PDM systems handle all the necessary data in design and manufacturing processes of the products (Crnkovic et al. 2003). These PDM systems are built on Data Bases (DB) which permanently store data in organized form. For the handling of the DBs the application of Data Base Management Systems (DBMS) is required. This will enable the users to store and handle data and assist them to evaluate, search, retrieve and track changes on the data (Ullman and Widom, 1997).

Generally a commercial DBMS system is applied to handle this kind of project data. In our case a self developed PDM system named intelliFiles (iF) was applied (Figure 6).

The iF has all of the important features of a commercial PDM/PLM system as listed in the following:

- functions to store and manage any kind of project data,
- query ability,
- data change management with logging,
- advanced backup and replication,
- security functions with user privileges management,
- change and access logging,
- file/document life-cycle support with different roles of the users,
- CE support with semi automatic communication.

Figure 6: The intelliFiles window

These functions show that the handling of such a complicated project like the design of an electric sports car can be supported with iF. Most importantly it enables a number of students working in parallel on the model while product data is kept organized and managed.

The previous sections illustrate that both the theoretical and technical conditions of the project are sufficient and well simulate the processes and methods applied in industry, therefore authors argue that the key aspects of an industrial PD process has been successfully implemented in an academic environment through an autonomous design project.

THE DIGITAL MOCK-UP

The ultimate target of the simulation project is the creation of a high complexity CAD model, a Digital Mock-Up, which is used in several fields of design and manufacturing. An active DMU has most of the properties of a physical product model, therefore it is a good subject of different VSs to substitute the physical tests.

Taking the design process into consideration – as already mentioned above – after the brief specification of the product the first steps of the conceptual phase were the creation of the exterior design (instantly modelled as a surface model in the and the CAD system) and the preliminary design of the drive chain.

Those two top-level systems determine the design since most of the car parameters are derived from these two main components. During the design of the DMU and its sub-systems all the participating students had to observe some highlighted rules.

Each part of the car has to meet the related standards, regulations and other applying rules. It was an important expectation towards participant students that all components have to be designed for manufacturability and in some specific cases the design of the manufacturing tool was also required. User requirements and consumer protection aspects have also been taken into consideration during the design of the concepts. Ergonomic studies have been executed on the components which are in interaction with the users. In these latter cases the design must meet the ergonomic requirements for the satisfaction of future owners' needs. There have been some examples when considerably different ones from the traditional solutions or rather innovative solutions emerged, then patent research were initiated.

Taking all those requirements into consideration in the DMU of the electric sports car the following components and sub-systems have already been developed and incorporated (see Figure 7 for visualization):

- exterior surfaces,
- drive-train,
- steering mechanism,
- brake system,
- monocoque central body part,
- auxiliary frames on at the front and rear,
- door concept,
- hood concept,
- rear-view mirror concept,
- windshield wiper,
- interior concept.

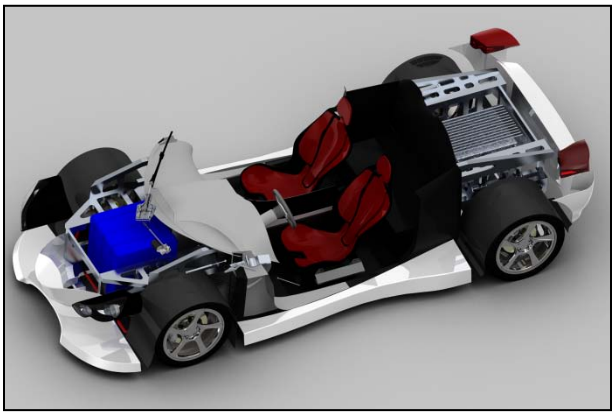

Figure 7: The Readiness of the Electric Sports Car

These tasks below are currently under preparation:

- detailed design of the car body shell elements,
- detailed design of the door and the side mirrors,
- detailed design of the interior of the car.

The listed tasks cover a working period of eight months and the high number and the complexity of the components well demonstrate the success of this project so far.

In this section the DMU was described as a product model structure, but on the other side of the application of the DMU there are the VSs executed by the students in relation with all components and sub-systems. A few of these simulations are introduced in the next section.

VIRTUAL TESTS ON THE DIGITAL MOCK-UP

Since the goal is to build a DMU, we aimed at carrying out all possible tests and simulations, the experimental application of the DMU can only be complete with the execution of the VSs. Some simulations were executed by the students based on their current knowledge in that specific field, but in some other cases students had to acquire new knowledge to succeed, or developed their competences by working with the DMU. The application of the learning-by-doing principle is found very useful according to the feedbacks from the students.

The first virtual test executed was the energy engineering simulation of the car. This VS was really essential in this special case of the electric sports car, as numerous other parameters were derived from the results of this VS in question. The simulation itself was oriented to map and estimate the total energy consumption of the car. During the execution of this VS the necessary energy and torque to move the car were calculated. On the basis of the results a specific electric motor was later selected. The other important component which significantly determines the arrangement of the car's drive-train is the battery pack. The battery cells were also selected upon the results of the previous VS and then the arrangement of the battery pack was finalized. In the next steps the auxiliary electrical devices were selected e.g. the steering servo, air conditioning unit, windshield wiper drive and the lighting instruments. After the selection of these components the energy consumption of the car was further iterated and evaluated. There came an idea about the possible application of outer solar cells to supply the auxiliary devices. The visible solar cells also make the car looking much more environment friendly and this would definitely be an attractive feature for the future owners. The main output of this VS was the total energy balance of the electric sport car.

The following simulations were parallelly executed by the students based on the method of the Concurrent Engineering. A car has to be a subject of many different ergonomic simulations since many components of the car are directly in interaction with the users. A VS was created to evaluate to what extent the selected and proposed components comply with the related regulations. These regulations are derived from the anthropometric measures of the human body. The applied CAD system provides tools to execute these ergonomic VSs. The software offers computer human models (i.e. manikin models) with various percentile dimensions. The application of these models proves the compliance of the design with the broad range of the population. These VSs included the vision evaluation from inside the car (Figure 8), the positioning of the steering wheel and the seat, the positioning of the rear-view mirrors and finally the reach simulation of the operator instruments and buttons.

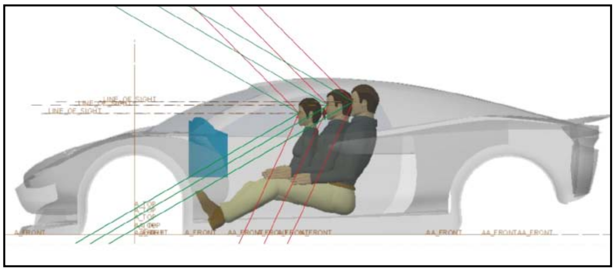

Figure 8: The Ergonomics Simulations: The Vision (Field of View) Evaluation

The simulations and tests commonly used in engineering design practice were applied in a wide range. Student teams carried out interference tests for instance. Furthermore, many kinematic and dynamic simulations have been executed during the project, e.g. the dynamic simulation of the suspension components was of absolute necessity because of the high load of the built in parts. On top of these previously mentioned simulations many other finite element analyses were executed in the field of mechanical and heat transfer processes. The majority of the simulations focus on the critical components of the car. These virtual simulations have took out many future physical tests.

CONCLUSION AND FURTHER RESEARCH

The simulation of an industrial project has many useful aspects. Practical results like the experiences from the process simulation of the project or the DMU finally realized can be presented. The educational requirements are all fulfilled, as students get the access to the latest IT tools, they learn theory and practice (learning-by-doing) in good balance. The virtual simulation of an industrial project can always be tailored to the needs of the HE institute and the students.

However, BME is not only an educational institute but also a research university. This is the reason why this project is being approached from the scientific point of view. The realization of this project can also be considered as a scientific achievement since it required a detailed background research and on the fields where insufficient or even the lack of tools or methods were detected, bespoke or customized tools or methods have been developed for the purpose of the project. One great example would be the process management method developed, the other would be the DBMS; this special IT tool has been specially customized to suit the requirements of this VS. Besides, further scientific results created at the university were utilized or tested in the frame of this project. The participation in the concurrent scientific research is not only available for the university researchers, but many students are also involved to this project, e.g. students wrote their diploma projects about working on the virtual sports car project. Two research areas must be highlighted in this project.

One research area is related to the processing of the monitored data of the project execution. This research focuses on a mathematical model to simulate and track the special risks in the design process. The risk assessment is based on fuzzy method like published by Retter (2007). An average project execution is loaded with different risks which is particularly typical in the design processes (DashWu et al. 2010) therefore any new mathematical model oriented to handle these risks might be of great step ahead in this field. The other research focus is related to the optimization and automatic set-up of the side mirrors. This concept is highly innovative, so it is under consideration to be patented. These two examples already well represent the scientific potential of this VS. This VS will surely triggers other research projects in the future and might turn some student's interest towards a scientific carrier.

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