Is what you see really what you get?

- Case study of virtual prototyping in designing the production process

Ilse Becker[1,2] and Ville Toivonen[2]
[1] Valmet Automotive
[2] Department of Production Engineering, Tampere University of Technology

This case study was conducted in a car manufacturing company where they used an immersive virtual reality system when designing the production process for a brand new car model. The process was designed simultaneously with the product development. The study is based on a user interview after the process was implemented in reality. Results concider the biggest gaps between working in a virtual environment and with physical models. Also some general thoughts of virtual reality system requirements are presented.

1 Introduction

This paper presents the results of using immersive virtual reality (VR) in prototyping a new car to the production in order to design its assembly process. The process was designed simultaneously with the product development. The product design was done in a newly founded company located in the US whereas the manufacturing company was very experienced and located in northern Europe. The target was to frontload the project as much as possible to reach the time to market quickly enough. Simultaneous engineering was the core function in realising this target. The geographic locations and difference in time made this a challenging issue. This study shows the manufacturing company's point of view. Figure 1 shows how the whole process worked in designing the product simultaneously with the assembly.

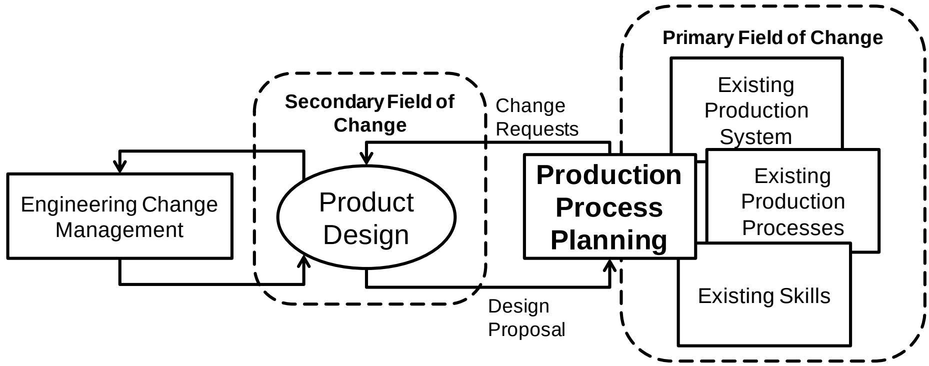

Figure 1: The SE teams propose their ideas to the product design when planning the assembly sequence within the line stations. This is an ongoing discussion until the final design is ready

1.1 Valmet Automotive – Case Company

The case company is located in the southwestern part of Finland. It has been manufacturing cars for over 40 years for traditional OEMs (Original Equipment Manufacturer). In the beginning of the 21st century the company's strategy was expanded from contract manufacturing to service providing. This meant among other changes that its manufacturing role was expanded more towards simultaneous engineering by designing the production process at the same time as the product is being designed and in collaboration with the OEM. Traditionally, very soon after the concept phase, physical prototypes are built to get an impression of the product and its manufacturability. In 2008 the company made an agreement with its first customer of the new era. The partners agreed that the car should be developed simultaneously with the production. Time to market pressure existed and led to a situation in which the production process had to be designed by virtual prototyping. That is why the case company decided to test its first immersive virtual build system to design the assembly process. In addition, they decided to conduct a pre-study to find out, what are the advantages of virtual build for them, and what properties are needed in the system in this context. By using the immersive virtual reality system in the production process design, the cooperation partners wanted to get as near the DfM (Design for Manufacturing) and DfA (Design for Assembly) targets as possible. This kind of early design can be compared to making movies, as illustrated by the filmmaker Howard Hawks's comment in the Chicago Tribune interview: "The one thing I've learned about making movies is that you can't fix a film once the shooting begins. If it's not right in the script, the problems are only bigger as the images move from paper to the big screen."[1].

1.2 Simultaneous engineering teams in the case company

There were four simultaneous engineering teams in the assembly department in this project's organisation. The teams were based on the module structure of the vehicle: powertrain and chassis, interior and HVAC (heating, ventilation and air conditioning), exterior and closures, electric and info&control. Each team had members from different departments in the case company: change management, process planning, assembly teams, production technology, internal quality, supplier quality, logistics, purchasing.

Most active participants in the virtual build sessions where the production process was planned came from the first four departments. Also the quality departments were represented but not so actively. That is why the interviewees in this study were chosen from those active departments. The questionnaire was sent to 30 persons, 10 of which gave their answers by email. Three from the eight persons were process planning and assembly team members from the assembly department, four were change management engineers and two were production technology engineers. One answer was got from an internal quality engineer but he answered only one question. The responsibilities in their team roles were the following:

Process Planning was responsible for planning the assembly process and they had to take into account the parallel production of another car model manufactured on the same production line. They also had to inform the construction about their requirements and to take the construction into account when planning a capable manufacturing process

The production team leader was responsible for telling the production's requirements to the construction and planning the production line balancing together with the process planning, from the realiser's point of view. They also supported in solving the problems concerning the assembly as well as taught the manufacturing staff in their own area

Change Management was responsible for acquairing the knowledge of all the product data and specifications which were created in the product development company as well as engineering changes. They had to inform the other team members about issues when it concerned the planning of the production as well as to prepare the MBOM (Manufacturing Bill of Materials) out of EBOM (Engineering Bill of Materials).

Production Technology was responsible for informing the team about the requirements and possibilities of the manufacturing equipment and prepare the alternative calculations of them if needed.

Figure 2: SE Team with moderating consultant in planning the assembly sequence virtually

2 Research in virtual prototyping when planning the production process

The case company benchmarked three different virtual reality systems during the production design process. The interview study in this paper is based on the usage of the company's first VR system which was rented for half a year. The benchmark study is presented in another paper by the authors [2].Different kinds of systems were found with various features. Regarding the assembly, some system features were essential for virtual prototyping. Product design on the contrary needed other features. Although common for both of them was the collision detection feature. No literature about similar cases was found where the target was to design the whole assembly process sequence of a brand new vehicle designed by a brand new company collaborating for the first time in a tight schedule. The virtual system technologies have been developed a lot in the past ten years and the starting point for today's research is different than it was in the millenium's change.

Dewar et al. [3] (1997) have been researching an assembly planning system which uses virtual reality. They said that there are two major tasks which the virtual assembly tool has to capture, the assembly sequence and the method of joining components together. They found out that the lack of force feedback when the objects collide as well as the relative accuracy of affordable tracking systems and imperfect depth perception are obstacles that occur when using virtual reality for assembly planning.

Jayram et al. [4] (2007) have been researching virtual assembly with a tool developed by them called VADE (Virtual Assembly Design Environment). In their case study of assembling the fifth wheel to a truck chassis, the downstream value to ergonomics was evaluated. However, their study focused on individual subassemblies.

Bullinger et al. [5] have been studying virtual assembly together with concurrent engineering developing "right first time" -methods like virtual assembly planning and ergonomic prototyping. In their method Virtual ANTHROPOS – a virtual model of a person – was applied. Also assembly sequencing was part of their research (2000).

Volkswagen has been using virtual reality in their company for quite a long time, since 1994 [6]. The software and hardware possibilities were much more limited at that time. The term VRAD (Virtual Reality Aided Design) is used in Volkswagen. The scope in virtual product design differs from the scope in designing a virtual assembly production process. In order to produce cars of top quality, the production process needs to be designed simultaneously with the product so that the product engineering design receives feedback from the production engineers and their requirements, thus resulting into an optimal process designed and implemented.

Simultaneous engineering and virtual assembly process have been developed and tested with good results for instance in a rock crusher manufacturing company [7]. Even though engineering design and production departments involved in simultaneous engineering were from the same company, the virtual assembly sessions were facilitated by a sub-contractor. Utilization of VR improves communication and collaboration between engineering design and production. It also enables better human requirements management, better safety and ergonomics, cost effective verification and documentation process, and increased productivity. The process included data conversions from CAD to VR, but the biggest bottleneck was the lack of a common PDM. Especially feedback, such as deviations, from reviews should be attached within the model and transferred back to PDM.

In the traditional automotive industry simultaneous engineering and collaborative design is not a new phenomenon. E.g. Toyota is one of the most famous companies who has made use of this practice to a great extent [8].

Also many other traditional automotive companies are using simultaneous engineering in this manner. But when it comes to automotive companies who are cooperating for the first time, with no previous common history, the situation is more complicated.

Ye et al. [9] have compared the assembly planning in three different environments (1999), traditional engineering environment, virtual nonimmersive CAD environment and immersive virtual environment. The results revealed advantages of the two VR environments over the traditional engineering environment in improving the subjects' overall assembly planning performance and in minimizing the handling difficulty, excessive reorientation, and dissimilarity of assembly operations. They have noticed the same facts as the case company of this study: Many factors must be considered in assembly planning. For example, production engineers must examine the geometric design of an assembly to ensure a feasible assembly sequence that does not induce part collisions and part trappings. Production engineers also need to look into other factors such as the reorientation, directionality, stability, manipulability, and parallelism of assembly operations, as well as the complexity of tools and fixtures. The study itself was very detailed in defining the assembly sequence for an air cylinder which consisted of 34 parts. Zhenyu et al. [10] have studied recording and edition of assembly sequence and assembly path. Recording was also used in the case company in difficult assemblies.

Today it is widely understood that if the product is already in the early development stage designed simultaneously for manufacturing process, it will save costs as well as in manufacturing time, one reason for that being that the possible needs for changes occur earlier. Eg. Fricke et al. [11] write about front-loading of the changes in a product development project as well as "Rule of 10" that also many other authors recommend. This rule means that if a change in a later phase is ten times more expensive than a change in the previous phase you can have ten times more changes in an earlier phase at the same cost. Choi et al. [12] have studied virtual assembly tools for improving product design. They say that a successfull implementation of DFMA (Design for Manufacturing and Assembly) requires cultural changes which lead to better communication among all levels of the organisation, promotion of team spirit, and an integrated involvement in product and process design. In our case this was even more demanding because the product and process design done in separate companies.

3 The Case study

The starting point and hypothesis in this study was that VR as a tool is a necessity in the projects of the new era. The aim was to find out, how well a production process design succeeded in real life when it was planned virtually.

The study itself was based on a real situation where the assembly process was designed virtually before any physical parts were available. In earlier projects the case company had always had a physical prototype car with which they did the sequence planning. Now they did the similar planning with immersive virtual reality system.

One experienced process planning engineer made the first draft of the assembly sequence. This proposal was then reviewed together with the assembly teams. The planned sequence had to fit the present manufacturing line where there already was another car model in production. Figure 3 presents the basic idea of the production line with the assembly stations. Also the subassemblies like the instrument panel and doors and their sequences were designed in the same way.

One interview was conducted among the participants in virtual build during the benchmark study. That was done in the early stage when they had not yet experienced the effects in the real production. Nine participants were interviewed by using a questionnaire. The participants were mostly experienced team leaders from the general assembly. During the new project they had learned to use CAD in analyzing the product subassemblies. Previously they worked mainly with the physical parts. In the interview they were asked what was their opinion of analysing assembly issues with the VR tool was when compared to 3D CAD, and how effective the VR was in solving assembly problems and if they noticed any benefits in learning the new product with VR.

The previous study focused on the features of the available VR software and hardware systems and which of them would best suit the case company's needs. One of the tested systems was in use for half a year and the virtual sequence planning was done with that software. The interviewee's answers are based on that software. Eg. the cable harness bending feature in that software was not used, because it was too complicated.

Almost everyone (eight out of nine) said that VR increased clarity compared to a regular screen projection very much or greatly (four or five on a scale from one to five). It also helped in learning a new process. Also many (eight), said that the system speeded up problem solving very much or greatly. Comparison in this first interview was done against 3D CAD usage, whereas in this second interview study VR usage is compared against reality.

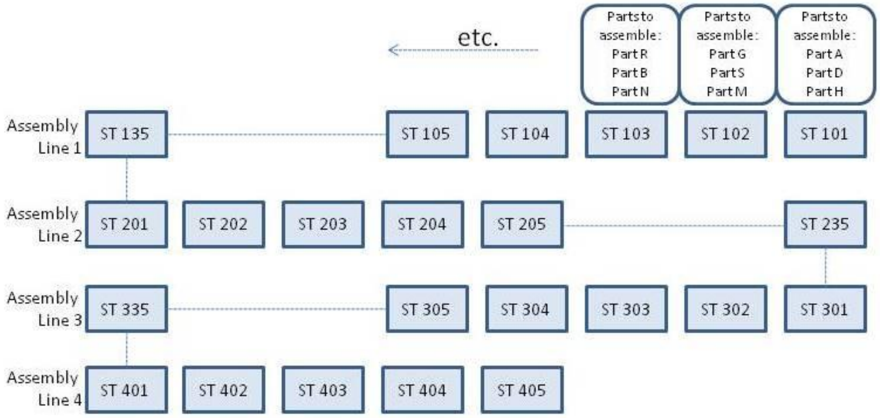

Figure 3: The assembly station layout and lines in the process

3.1 The interview methods

The interview method was qualitative allowing the interviewees to express their opinions more freely. The questions were sent by email to all active participants of the virtual build which was 30 people. Answers were got from 10 people and one of them answered only one question. The following chapter represents the questions and results of the interview.

3.2 The interview results

The interviewees answers were expressed in their own words and they are summarized in the table 1. The interviewees were asked to answer the questions presented in the table, comparing the assembly sequence planning that uses a virtual prototype with that of using a physical prototype.

Table 1: Questions and answers summary

What were the differencies in the resulted assembly sequence between these two methods?	The virtually resulted assembly sequence was mainly suitable also in real life. Soft parts like wire harnesses caused some changes afterwards. Anyway the worst failures in product design from assembly point of view were captured
What assemblies were not possible to study virtually?	Assembly dimensions and tolerances were not possible to study virtually as well as the gaps between eg. the exterior parts like fascias to fenders.
What implications had the previous lack in the planned production process	Part behaviour, assembly tolerances and difficulties in collision analysis as well as specifying the assembly tools caused that the assembly time and sequence could not be specified exactly
What is your note for the goodness of the virtually planned assembly sequence?	Average is 7 (scale 1-10). The best ratings were given by the people who designed the assembly process. The worst rate was given by an engineer, who had to prepare the sessions.
What were the biggest miscalculations?	The virtual build gave maybe a little bit too optimistic picture of the assemblies because the part features could not be simulated. This was one reason for wrong assembly time estimations.
Which issues lend themselves best to reviewing in virtual reality?	Planning the assembly sequence, evaluating the ergonomy and assembly of non-elastic parts like interior, motor, subframe as well as assembly of single subassemblies.
Does the virtual reality system suit for training of the assembly personal?	If you have not got real parts yet. Best way is still learning by doing and virtuality can give a picture for the assemblers in advance of the product and assemblies.
If yes in which way then?	By going through the assembly sequence and parts and analysing and discussing the details in the team.
What else should be kept in mind with the next new product process design with VR system?	The planning should be started early enough keeping in mind the uncertainties of the process. The VR system's usability is important as well as enough trained users to operate the system. The CAD model management should be in good shape to have the accurate revisions on hand.

4 Conclusions

The interviews verified the immersive virtual reality system's necessity in today's production line sequencing. If the production line design has to wait for the physical prototype parts, product design does not get feedback from manufacturing and the simultaneous engineering targets are not reached.

Another important target is the time-to-market which is a crucial success factor in a car project's market competition.

It was also useful to get the production staff's opinions documented and analysed for the future projects. What was interesting was that those from the interviewees who worked near the production line, and were very experienced on their own field but had limited experience in digital product data system usage, were more positive about using the VR and about its benifits. The change management and production technology engineers, who worked in production supporting functions and had more experience in CAD systems, were not as positive. The reason might be that the VR system used in this case study needed a lot of preparation before a session could start.

To get back to the question if what you see really is what you get, the study has shown that when planning the assembly virtually you do not get exactly the same result as in real life. In the sequence planning one has to keep in mind that it is not possible to design the sequence completely virtually because not all parts are acting realistic, e.g. wire harnesses and hoses. Neither was it possible to get force feedback in the assembly. However ergonomy investigations were found very useful with virtual build, especially since the case vehicle's body was quite big. For those assemblies that could not be tested virtually, eg. tolerances and flexible parts, it might be good for every module to have a special engineer in charge who does it on his desktop with the CAD software. Assembly ergonomy testing could also be separated as an individual task of an expert.

One very important aspect to be considered is the usability of the system. The tested system which also was the basis for the interview was not user friendly. The sessions had to be prepared in advance by converting all the CAD files to the system‘s format. It sometime happened that the converted CAD file was not the latest revision and a new conversion was needed. Because the conversions took quite a long time they were conducted the evening before. One of the conclusions is therefore that user friendliness and accessibility of the virtual system is essential for an immersive VR system. This holds especially when the product models are subject to repetitive change and there are multiple people attending the planning sessions.

The amount of project organisation in the case company is low and the teams are used to working in a self-organised way. Also the VR system should support independent groupwork and enable fast setup of planning sessions without considerable external work effort. When the software is the same as the CAD design software this is possible in principle but it also requires trained personnel. In any case the company has to have someone who is responsible for the VR room and equipment usage.

5 Discussion

The interview was based on working with rented test equipment. Now the case company has installed an own immersive VR system of its own where the software is part of the CAD software used in the company. That is a big advantage because it does not require conversions to the CAD files. Further research could show how well the system is working and whether the chosen features of the system are suitable in real life, and how well the system will be adopted in the company's organisation.

Haptic technology has not been used in the case company's virtual planning but it would also be an interesting trial for some subassemblies. Another interesting subject for investigation in later project phases in the case company might be augmented reality. Also software features with bending of flexible parts would be a useful new add-on to the virtual build.

It would also be interesting to study the VR usage in other case companies when designing the production process and assembly sequence. Another interesting research topic would be to analyse the change proposals that the manufacturing teams made to the product design during the simultaneous product development. The questions would then be, how many of the proposals are realized and what are the savings in time and money in consequence of that.

References

[1] Campbell, R.G., Roth, E.S. Integrated Product Design and Manufacturing using Geometric Dimensioning and Tolerancing. 2003. Marcel Dekker, Inc.

[2] Becker, I.; Toivonen, V., Leino, S-P.: "Using virtual reality in designing the assembly process of a car", 13th International Design Conference - Design 2011, Copenhagen.

[3] Dewar, R.G., Carpenter, I.D., Ritchie, J.M., Simmons, J.E.L.: "Assembly planning in a virtual environment", Innovation in Technology Management - The Key to Global Leadership. PICMET '97: Portland International Conference on Management and Technology

[4] Jayaram, S. Jayaram, U., Young, J.K., DeChenne, C., Lyons, K.W., Palmer, C., Mitsui, T.:"Industry case studies in the use of immersive virtual assembly". Virtual Reality, Vol. 11, No. 4, pp. 217-228, 2007.

[5] Bullinger, H.J., Richter, M. Seidel, K.-A. Virtual Assembly Planning. Human Factors and Ergonomics in Manufacturing. Vol. 10 (3), 331-341. 2000

[6] Zimmermann, P. Virtual Reality Aided Design: A Survey of the Use of VR in Automotive Industry. Advanced Summer Institute on "Product Engineering: Tools and Methods based on Virtual Reality", 30th May-6th June 2007

[7] Leino, S.-P., Kiviranta, S., Rantanen, P., Heikkilä, J., Martikainen, T., Vehviläinen, M., Mäkiranta, A., Nuutinen, P., Hokkanen, I., Multanen, P. (2010) "Collaboration between Design and Production by exploiting VR/AR and PLM - Case Metso Minerals" 3rd International Conference on Applied Human Factors and Ergonomics - AHFE2010. 17- 20 July 2010. Miami Florida USA

[8] Morgan, J.M., Liker, J.K., The Toyota Product Development System: Integrating People, Process And Technology. 2006. Productivity Press.

[9] Ye, N., Banerjee, P., Banerjee, A., Dech, F.: A Comparative Study of Assembly Planning in Traditional and Virtual Environments. IEEE Transactions on Systems, Man, and Cybernetics—Part C: Applications and Reviews, Vol. 29, No. 4, November 1999.

[10] Zhenyu Liu, Jianrong Tan,: "Virtual assembly and tolerance analysis for collaborative design", Computer Supported Cooperative Work in Design, pp. 617 - 622 Vol. 1, 2005. Ninth International Conference on Computer Supported Cooperative Work in Design Proceedings.

[11] Fricke, E., Gebhard, B., Negele, H., Igenbergs, E. Coping with Changes: Causes, Findings and Strategies. Systems Engineering, Vol. 3, No. 4, 2000, pp. 169-179.

[12] Choi, A. C. K., Chan, D. S. K., Yuen, A. M. F., Application of Virtual Assembly Tools for Improving Product Design. International Journal of Advanced Manufacturing Technology. 2002. Vol. 19, pp. 377-383.