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Life-cycle of simulation models: requirements and case studies in the automotive industry

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There is a tendency to maintain and use some simulation models, once implemented, over a period of several years. This article discusses a couple of reasons for the increasing long-term use of models. Two cases from the German car manufacturer BMW Group are presented to illustrate the particular technological and organizational challenges related to the application of simulation models for almost a decade.

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1. Introduction

In the field of simulation in production and logistics the term life-cycle is used in different connotations. Sargent *et al* (2006) distinguish the project life-cycle of developing simulation models (project life-cycle) from the life-cycle of simulation models, which may be considered as products (product life-cycle). In the literature, the project life-cycle typically is discussed as part of procedure models for simulation (Rabe *et al*, 2008a). The main purpose of those procedure models is to provide steps and guidelines for a professional and structured performance of a simulation project. Surveys on procedure models for simulation can be found in Rabe *et al* (2008b) and Nance and Arthur (2006). A third combination of the terms simulation and life-cycle is centred around the real-world production and logistics systems under consideration: simulation may be used in each phase of the life-cycle of a production and logistics system. In this context the life-cycle phases planning, implementation and operation are mentioned in several publications (Kosturiak and Gregor, 1999; Klingstam and Olsson, 2000; VDI, 2008).

In the remainder of this article, life-cycle phases such as planning and implementation will also have to be considered; however, the emphasis will be on the life-cycle of simulation models itself (product life-cycle). In this respect simulation models with a long life-cycle are at the heart of the following discussion. Ulgen and Gunal (1998) rate 20–30% of simulation models to be used for a long term. According to their definition long life-cycle simulation models are used throughout multiple points during the life-cycle of the investigated real-world system. Additionally, they are maintained and revalidated to reflect changes of the system. On the other hand, short life-cycle simulation models are used for decision making at a certain point in the life-cycle of the real-world system (eg only at the beginning of the planning phase) and these models typically serve a single decision-making purpose.

Over the past decade the use of long life-cycle simulation models in the automotive industry in general and within the BMW Group in particular most likely exceed the 30% given by Ulgen and Gunal (1998). The second section of this article will outline several reasons for the increase in long-term model use throughout the German car manufacturers. The third section gives two examples for long-term model use presenting simulation applications for two plants of the BMW Group. Some of the specific technological and organizational challenges that came up during those applications are discussed in the fourth section. Section 5 summarizes the main aspects of this article.

2. Reasons for long-term model use

The increasing long-term use of simulation models in the German automotive industry has a number of reasons. First of all, the general conditions for manufacturing engineering have changed. Greenfield investments have become an exception. Instead, new production facilities have to be integrated in existing plant structures. This changing investment paradigm from greenfield to brownfield tends to support the long-term use of simulation models: If there is already a simulation model for existing plant facilities, it may well be reasonable to use the existing model in order to save time and money when setting up the simulation for the new facilities.

Another reason is the growing trend to adapt emulation methods in the automotive industry. Emulation, that is the connection of actual real-world control systems to simulation

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models in order to test the operation of the controls (cf. Johnstone *et al*, 2007) has been adapted by, for example, the BMW Group just during the past couple of years (cf. Mayer and Burges, 2006). Some of the simulation models used for emulation purposes are build based on models which originally were applied differently: Many emulation models are derived from simulation models that were implemented to support planning processes. Furthermore, emulation is not only used for the initial commissioning of a real-world control system. Actually, an emulation model can be used throughout the whole life-cycle of the control system supporting the rollout and commissioning of each new software release. Thus, the trend to emulation strengthens the trend to long-term model use.

Similar to emulation, that is used throughout the ramp-up of a real-world logistics and production system in first place, the acceptance and the number of simulation-based software applications are growing. Those applications typically part of the daily operation of a real-world system, for example, to support dispatching processes. The BMW Group has implemented several online and plant-wide simulation models to compute daily forecasts on plant output and on production sequences. These models are equipped with interfaces to production control systems. It is possible to initialize and start the models with the current production status. With only a few exceptions, these plant-wide models are used for a couple of years, for example, for the life-cycle of a vehicle type or while a certain product range is produced in the plant.

A fourth reason is that the analysis of the overall carbody manufacturing process from body-in-white to final assembly is getting increasingly important. This is partly because of the growing insight, that good solutions for a part of the manufacturing chain do not necessarily lead to a satisfactory behaviour of the total process chain. Accordingly, the BMW Group considers simulation not only to be valuable for certain areas and departments but rather to be a tool to understand and improve processes between departments, for a whole plant or even between plants. The technological consequence is that simulation models for operations or areas such as logistics, body-in-white, paint shop or final assembly need to be connectable with each other. A fast and cost-efficient connection of simulation models requires the availability of up-to-date models of each relevant area. Thus, the tendency to comprehensive process chain simulation models also has an effect towards the long-term use of simulation models.

The connection of (sub-)models is not only of importance for process chain simulations. Within one area, for example, within the body-in-white, it is common practice to share the responsibility for modelling between several simulation experts. Here, commercial constraints come into play: large engineering and construction orders as the implementation of a new body shop are often placed in the hands of more than one contractor. Each contractor has to provide a simulation model for the production area it is supplying. In this context, the technological and organizational challenge from the simulation perspective is to build one integrated long life-cycle model from a set of locally implemented models.

3. Two case studies of long-term model use

The intensive use of simulation technology within the BMW Group dates back into the eighties of the last century. Manufacturing departments such as body-in-white introduced comprehensive application concepts, tackling challenges and investigating questions throughout all project phases as depicted in Figure 1 (cf. Griffel, 1999).

A consequence of the application of these concepts since many years is that there are several cases of long-term use of simulation models in the BMW Group today. This section provides two examples: the simulation model of the body-in-white production system of the BMW plant in Munich, Germany, and the simulation model for painted bodies (comprising body shop and paint shop) of the MINI plant in Oxford, UK. The first example conveys a good impression of the simulation requirements within one area (or department) of the manufacturing process chain. In addition, the second example highlights the role of process chain-related questions and of emulation.

The upper two thirds of Figure 2 provide a simplified overview of the vehicle types manufactured in the Munich and the Oxford plant, respectively. The lower third of Figure 2 shows the advances of the commercial simulation software package used at the BMW Group over the same period of time.

3.1. Body-shop simulation in the Munich plant

An important trigger for the implementation of a simulation model for the carbody shop in the BMW plant in Munich, Germany, was the integration of a new vehicle type (the BMW 3 series compact) into the existing manufacturing facilities. In a first step, the carbody assembly of the BMW 3 series saloon and of the predecessor of the BMW 3 series compact were modelled in order to validate the simulation model against the existing real-world manufacturing system.

Figure 1 Project phases in BMW Groups manufacturing engineering.

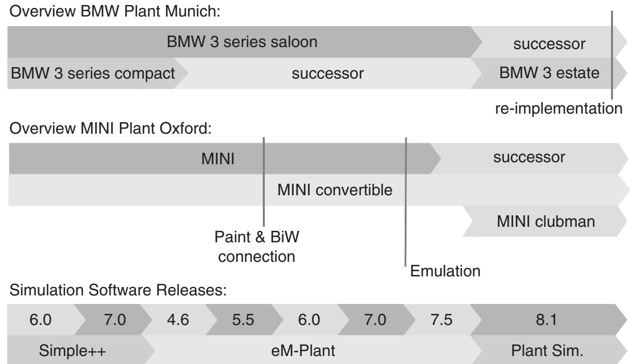

Figure 2 Produced vehicle models in the considered cases and available software releases.

After implementation and validation of this step, the facilities planned for the BMW 3 series compact successor were integrated in the simulation model.

During the ongoing planning process until start of production (SOP) of the new vehicle model, the simulation model was broken down in further detail. After SOP the responsible staff in the plant used the simulation continuously to analyse scenarios that came up in the daily operation of the shop. Additionally, several re-engineering projects (necessary because of changes in welding technology or in the conveyor system) were supported with simulation experiments.

In the year 2004, after five years of usage of the permanently modified and adapted model, the planning of the next generation of BMW 3 series saloon and estate (touring) started. Again, the existing simulation model was used to facilitate the planning process. Conveyors and welding equipment for the two new vehicle types had to be integrated in the simulation model. Moreover, since the production of the BMW 3 series compact was about to end, the respective elements had to be removed from the model. Very similar to the re-construction efforts in the real-world body shop, at first new equipment had to be added to the model and afterwards the dispensable devices had to be dismantled. After completion of the planning process and SOP of the new vehicle types the simulation model again served the plant staff in daily business having already done that by now for more than one vehicle model cycle.

Early in the year 2008, the simulation model which had initially been implemented in the year 1999 had been used (with several modifications) for almost 9 years. At this point in time, software issues urged a complete re-implementation of the model. In January 2008 the BMW Group switched to release 8.1 of the software package Plant Simulation. It turned out that the 9-year-old simulation model, implemented firstly by using release 6.0 of the predecessor simulation package Simple++ (see Figure 2), was not executable with the new software release. It was estimated that it would cost almost the same effort to adjust the existing model to the new software release as to do a complete re-implementation of the model. The latter was of course done using the existing model as the almost ‘perfect’ specification. Since simulation had proved itself to be of great value for the plant, there was not much hesitation to invest time and money for the re-implementation.

3.2. Painted body simulation in the MINI plant Oxford

The initial implementation of the simulation model for the MINI plant Oxford has its roots in requirements dating back to the year 2001. At that point in time, a number of different actions were discussed to match the growing demand for the MINI and the MINI convertible. The selection and the prioritization of these actions should be supported by a simulation model. Once built, the model was used similar as the Munich model to support issues coming up during daily plant operation with a focus on the development and verification of control rules for the body shop conveyor system. Also in similarity to Munich, the simulation model became part of the planning of new vehicle types (see Figure 2). The facilities for the MINI and the MINI convertible successors were planned based on simulation results and so were the integration steps of the new MINI Clubman.

In the year 2004, the MINI plant Oxford faced various challenges: the demand for all MINI derivatives was still growing rapidly, the number of carbody variants was gradually increasing and the requirements of the ‘customer-oriented sales and production process (KOVP)’, BMW Groups built-to-order program (Pietsch, 2002; Reichart and Holweg, 2008), were imposed on the production process. To tackle these challenges it was decided to model not only the body shop but the overall manufacturing process chain of the painted body. This is based on the concept of considering the painted body to be one important subassembly of a vehicle. One major purpose was to gain insights in the reliability of the process, namely in the sequence adherence of the supplied painted bodies to the sequence required at the entrance of final assembly.

Accordingly, the production in paint shop was modelled in detail as well (in a separate simulation model). Both the paint shop and the body shop simulation model were enabled to be connected with each other. The connected model, comprising two large manufacturing areas including paint shops downstream buffer to final assembly, made it possible to identify bottlenecks in the overall painted body manufacturing process and to derive and test measures to lift the bottlenecks appropriately. In this context, some new and more cost-efficient shift models for large areas of the production were evaluated.

The comprehensive painted body model was not only used for planning purposes but additionally to support the rollout of a new production control system in the MINI plant Oxford. The BMW Group implemented step-by-step a standardized software for production control in all its plants worldwide throughout the past couple of years. The introduction of such an application typically does have an immediate impact on production and does incorporate risks culminating in a possible standstill of a plant. Emulation is an approach to minimize suchlike risks (see Mayer and Burges (2006) for more information on BMW Groups production control system and for details about emulation techniques at BMW). In the case of the BMW plant Oxford, the interfaces to the production control system (already available from projects in other plants) were added to the existing simulation model thus creating an emulation environment very efficiently.

Today, the model has components that are more than 8 years old. It is still used to support short-term planning decisions in body shop, paint shop, or for the overall painted body manufacturing process. Additionally, the emulation capabilities are re-activated whenever a new release of the process control system is installed. From the simulation standpoint, this case brought up some specific challenges:

- Both the body shop model and the paint shop model have to be updated on a regular basis to match the current status of the real-world shops. Normally, different engineers are in charge of the two simulation models.
- The models of both areas are used separately but need to be connectable at any time for painted body scenarios.
- It needs to be possible at any time to use the model for emulation purposes meaning that the interfaces to the production control system need to be maintained with every model update.

The following section discusses several conditions that need to be met in order to handle these and other challenges that are coming along with long-term model use efficiently and effectively.

4. Conditions for a successful long-term model use

Both case studies presented in this article show examples of simulation models being used and updated for almost a decade. Such a long-term model use is complicated by some technological and organizational difficulties. Apart from the issues mentioned in subsection 3.2, there are the following factors:

- new releases of the simulation software packages on a regular basis;
- updates of the simulation building blocks supplied by the simulation software vendor or developed by simulation experts as add-ons;
- different update cycles for the different areas of a large simulation model (eg, in car manufacturing plants, changes to the body shop are driven by new vehicle types whereas changes in the paint shop are induced by different paint application technology);
- the responsibilities of a person in charge of maintaining a simulation model change;
- the person in charge of maintaining the simulation model changes;
- different simulation experts (internal and external) work on the same model.

These issues highlight the importance of standards for a successful long-term model use. In recognition of these circumstances, the BMW Group decided already in the mid-1990s to implement only one simulation software package across the group. This initial standardization turned out to be an important catalyst for the communication between the companies simulation experts working in different departments, for example, by easing and intensifying know-how transfer. Since then, a standard automotive building block library has been added to the simulation software package. This so-called VDA Automotive Building Block Library is developed and maintained by a working group of the VDA (German Association of the Automotive Industry; see Heinrich and Mayer, 2006). This building block library, supplemented with some BMW Group-specific building blocks, is the technological root for almost all implemented simulation models at BMW. According to BMW Groups simulation guideline, the use of the VDA building block library is mandatory in a simulation project. Additionally, the simulation guideline

- requires each simulation expert to stick to a set of regulations with respect to model structure, naming of model elements, comments in source code etc;
- specifies the application of a given simulation procedure model for simulation projects (model specification, modelling, model documentation);
- defines rules for file and directory names;
- postulates that models, wherever necessary or possible, need to be designed in a way that the connection to other models or the integration of interfaces to the BMW production control system is supported. Typically, this requires an adequate structure of the simulation models.

Even if those rules are obeyed and standards are applied, the connection of sub-models does depend on several very detailed requirements. In order to merge sub-models into one simulation model, the implementation of the sub-models needs to be based on identical (and not individually modified) releases of the building block library. This demands a great amount of discipline from all involved programmers and limits their flexibility to some degree.

Besides these mainly technological conditions discussed so far, it is only possible to maintain and refine simulation models over a long-term period, if the organizational conditions support this process. First of all, simulation needs to be established in the companies organization in such a way that resources for all associated activities are continuously available. Employees, once trained and qualified, must have the opportunity to work for a longer period of time, that is, for more than 2 or 3 years, with a significant portion of their capacity on simulation projects, simulation modelling, and experimentation. If a holder of a simulation position is about to change jobs (which is encouraged and stipulated in large organization on a regular basis), the acquired simulation know-how must not get lost. This requires appropriate concepts for training, adjustment and changeover of staff.

If all these technological and organizational conditions are met, there is a substantial basis for the application of simulation in general and for long-term maintenance and use of simulation models in particular. The greatest benefit of long-term model use is the shortened time to complete simulation tasks, since there is always an (almost) up-to-date model of the manufacturing system available. Thus, in some cases, no modelling is necessary to perform the simulation task. Instead, experimentation can be started right away using the existing model. To conclude with, as a lesson from the cases at BMW Group it can be learned that it is rather more efficient to maintain and update a large simulation model than to repeat the modelling for the same manufacturing area several times.

5. Summary

For some reason there is a tendency in the automotive industry towards long-term model use. Two cases in this article illustrated that the life-cycle of simulation models may last for 8 or more years. Standards as well technological (simulation software packages and building block libraries) as organizational (human resource development for simulation experts, guidelines for simulation projects) turned out to be crucial success factors to tackle the challenges imposed by long model life-cycles.

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