An Operational Application of System Dynamics in the Automotive Industry: Inventory Management at BMW

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Abstract. *The application of system dynamics modelling in strategic decision-making and the analysis of market scenarios has been widely recognized. However, little attention has been placed on the application of system dynamics models to support operational decision-making. This paper presents a simple system dynamics model developed for BMW's production planning department to support decision making on production schedule, -mix and inventory management on a day-to-day basis. As we will show in the paper, production planning in car manufacturing is characterized by high complexity and uncertainty due to various parameters influencing the inventory levels and production progress. In this situation a static monitoring of inventory levels is not sufficient for production planning, since the inventory levels are critical for the car production process to work properly. Therefore a dynamic monitoring tool is needed. Based on a relatively simple structure, an easy-to-use interface, and online data-exchange, the developed system dynamics model described in this paper offers a tool to assess the risk associated with different inventory policies and improves the management of inventories and production schedules. The paper concludes with the experience made during the last 1½ years, in which the model has been used by the production planners at BMW's production plant in Regensburg.*

1. Introduction

Ever since Henry Ford made his famous offer of "any colour as long as it's black", the position of a consumer, who is interested in buying a new car, has changed fundamentally. Today's automobile market is driven by rapidly changing consumer needs and tastes. The intense competition in the world automobile industry has forced the manufacturers to deliver high quality and value products, and build and sustain strong consumer relationships (Clark and Fujimoto, 1993; Wetlaufer, 1999). To fulfill the needs of sophisticated customers, manufacturers have steadily increased product variety and developed new product features. Moreover, manufacturers are exploring ways in which they can shorten the lead-time between a customer's order, and vehicle delivery.

The high level of product complexity and variety has a strong impact on the automobile assembly operations and the production planning process. Traditionally, the production management goal was to drive up the accumulated volume of production and so drive down costs through the realization of scale economies (Hill and Jones, 1995). Scale economies lower unit cost by spreading fixed costs (e.g. cost of machinery, administration, advertising, R&D) over a large volume of output. Riding down the unit-cost curve involved "pushing" a great number of unordered and standardized cars into dealer stocks. This is starkly opposed to modern manufacturing "pull" processes, in which parts are not made until they are needed by the next upstream step in the production process ("JIT" – Just in Time delivery or production).

The shift from mass production to lean production was driven by the need of higher quality, increased product variety and a more customer-oriented approach to manufacturing. The goal of lean production is to decrease inventories and to reduce the waste of time and material in the manufacturing process, thereby increasing production efficiency and product quality (Womack et al, 1990). The "Three day car" (three days from customer order to delivery) is the vision at the end of the "lean" development, and car manufacturers around the world pursue "built-to-order" strategies to produce cars, which exactly meet customer expectations (for details see Anderson, 1996; Graves and Warburton, 1999).

The described trends of "pull"-oriented manufacturing and distribution processes have lead to fundamental changes in the manufacturing technology and the requirements of the production planning and control process. Production planning has become a highly complex process and has to deal with various parameters, influencing inventory levels and production throughput (see section 3 for details). Standard PPS systems (computer-based Production Planning and Control Systems) or static spreadsheet planning are not capable of supporting the operational production planning process in a dynamic and uncertain environment. Therefore, we have developed a system dynamics model for BMW's production-planning department to support decision making on production schedule, -mix and inventory management on a day-to-day basis. Based on a relatively simple structure, an easy-to-use interface, and online data-exchange, the developed system dynamics model offers a tool to assess the risk associated with different inventory policies and improves the management of inventories and production schedules. Before explaining details of the planning process in section 3, we will have a closer look at the production site and the manufacturing process in section 2. Section 4 gives an overview of the problems in the planning process and motivates the need for a simulation tool, based on a system dynamics model. In section 5 we will describe the developed simulation tool in more detail. Section 6 summarizes the experiences we made with our approach at BMWs plant in Regensburg, Germany. Finally, section 7 concludes the paper.

2. Production Site and Production Process

Since November 1986, BMW 3 series cars have been in production in Regensburg, situated on the banks of the Danube in Bavaria. Covering an area of 350 acres, the plant employs approximately 9000 workers producing 215,000 BMW 3 series (sedan, station wagon, coupe, convertible) per year. The manufacturing process of an automobile can be divided into four major steps: 1) Stamping of the metal sheet blades in the press shop, 2) Welding of the parts in the white body shop, 3) Painting of the car body in the paint shop, and 4) the final assembly of the car. Figure 1 illustrates this process.

The production process begins with metal sheet blades that are stamped in the press shop. Then the stamped body parts are welded together in the white body shop to create a car body. Before the car body is painted in the paint shop it is stored in a stacker called *white body stacker*. Since the painting process works optimal if bodies to be painted with the same color follow immediately one after the other, the white body stacker is used to sort the bodies produced by the white body shop. The aim is to build clusters of approximately 20 bodies to be painted with the same color. Before the painted bodies go to the assembly area, where several thousand parts are added on an assembly line, they are stored in another stacker called *painted body stacker*. 3series sedan cars, coupes, convertibles and touring models are produced in varying sequence. On the assembly line, the aim is to achieve an optimum mix of vehicles. Each vehicle is being built according customer order and assembly thus needs to take into account a wide diversity of customer order wishes. The stacker is used to determine a sequence of cars on the line, which ensures an even distribution of the workload amongst assembly workers. Thus the painted body stacker is used to sort the painted bodies in a way to support an optimal assembly process.

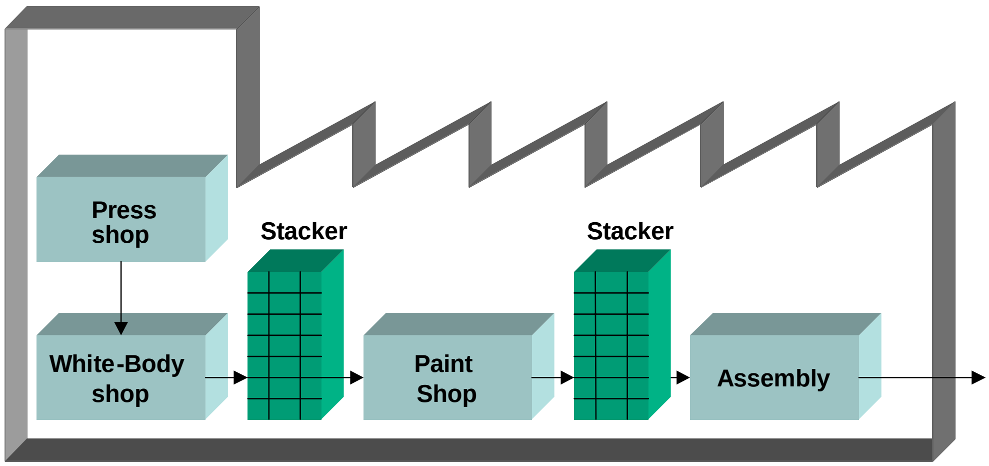

Figure 1: Overview of Manufacturing Process

The assembly line is divided into three main sections: trim, chassis and final assembly. Lightweight parts are installed in the trim section, while heavier parts, such as the engine and transmission, are installed in the chassis section. The production process ends in the final assembly, where a number of small operations are performed, such as filling various fluid reservoirs, making numerous quality checks and conducting minor repairs as necessary.

The parts supply process supports the assembly line. This process starts with a supplier plant producing a part and ends with the part arriving in an assembly worker's hand as the car requiring that part enters the workstation. Supply plants are provided with build schedules via an electronic data interchange network with sufficient lead-time to deliver the required parts when they are needed. The plant in Regensburg uses several Just-in-Time supply relations to deal with product variety. The cars produced by the plant Regensburg vary along several dimensions, including body stile, exterior and interior color, harness, power train and choice of options.

Looking in more detail at the described production process there are many possible circumstances which raise problems due to the production process, such as downtimes of robots in the white body shop, increase of repainting because of paint process problems or downtime of work stations in the assembly line. Many of these problems influence the inventory levels of the white body stacker and/or the painted body stacker. Another important factor influencing these inventory levels is the operations time of a production department. At the plant in Regensburg the white body shop uses a different shift model with different operations times than the paint shop. Therefore the white body stacker must be able to buffer sufficient white bodies to compensate these variations in operations times. Similarly the painted body stacker must be able to buffer enough painted bodies due to different shift models between the paint shop and the assembly shop.

3. Production Planning and Control

At BMW's production plant in Regensburg the production-planning department is responsible for planning and controlling the production schedule and –mix, including the management of the white body and the painted body stacker. Four basic functions can be identified: planning, dispatching, control, and taking of corrective action if the actual performance deviates from the planned performance.

In the *planning phase* the production schedule and the production mix (i.e. the ratio of sedan, coupe, station wagon, convertible of the whole production) are planned. Typically the period that is planned for is one month. Note that planning starts several weeks before the actual start of production and the production schedule has to be fixed two weeks before actual production starts. In car manufacturing production planning is characterized by high complexity and uncertainty because various parameters, such as operations times, capacity of the white body stacker and the painted body stacker, changes in production mix, changes in production capacity, and various time delays, such as the time a car body needs to go through a production area or the time a body is stored in the white body stacker resp. painted body stacker, have to be considered.

The function of *dispatching* puts the plan into effect, that is operations are started in accordance with the plan. In the operating phase the production-planning department has to observe and *record the actual performance* of production, e.g. it monitors the inventory levels of the white body and the painted body stacker. Typically this is done on a day-to-day basis. The actual performance is compared with the planned performance, and when required, *corrective action is taken*. This happens, e.g. if the inventory levels of the white body and/or painted body stacker get too low or too high or if problems in the production process occur. Finding out the right steps to correct the inventory levels is also characterized by high complexity and uncertainty because of various parameters and various time delays.

4. The Problem and the Need for a new Tool

The objectives of production planning and control are to fulfil customer orders in time, reduce inventories and throughput time, and to establish schedules for work that will ensure the optimum utilisation of materials, workers, and machines. As the description of the manufacturing process shows, production planning in car manufacturing is complex, because a *large number of constants and constraints* have to be considered, such as operation times, stacker and production capacity, and other constraints imposed by the underlying manufacturing system. Moreover, the planner has to take the *dynamics of the system* into consideration, that is time delays, handling and process times are important variables in the planning process. Even worse, the planning process is characterized by high *uncertainty*, because downtimes or delivery problems of suppliers can cause production losses and require changes in the production schedule in the short run. In the latter case, the impact and timing of such changes cannot be foreseen and considered in the long-term planning process and challenges the planner to meet the master production scheduling despite of the occurring problems.

Standard PPS systems facilitate long range and rough-cut production planning. However, they are not capable in coordinating the operational planning process in a multistage production system due to the high complexity of such systems (Arnold et al., 1997). Adapting the system to the process ("customising") and refining the planning process requires reprogramming of the software, which is costly and time consuming (Arnold et al., 1997). Especially, the difficulties in implementing changes in the production schedule in the short run was criticized by authors (Milberg and Burger, 1991; Arnold et al., 1997) and a better support for the operational planning on a day-to-day basis was requested (Milberg and Burger, 1991; Eversheim und Thome, 1988).

To bridge the gap between the described requirements of the production-planning department and the long range planning function provided by the central PPS, we have developed a dynamic planning and monitoring tool with an easy-to-use interface and online data-exchange. The developed tool is based on a system dynamics model and puts the production-planning department in a position to assess the risk associated with different inventory policies and improves the management of inventories and production schedules. Figure 2 illustrates the planning process and the information flows.

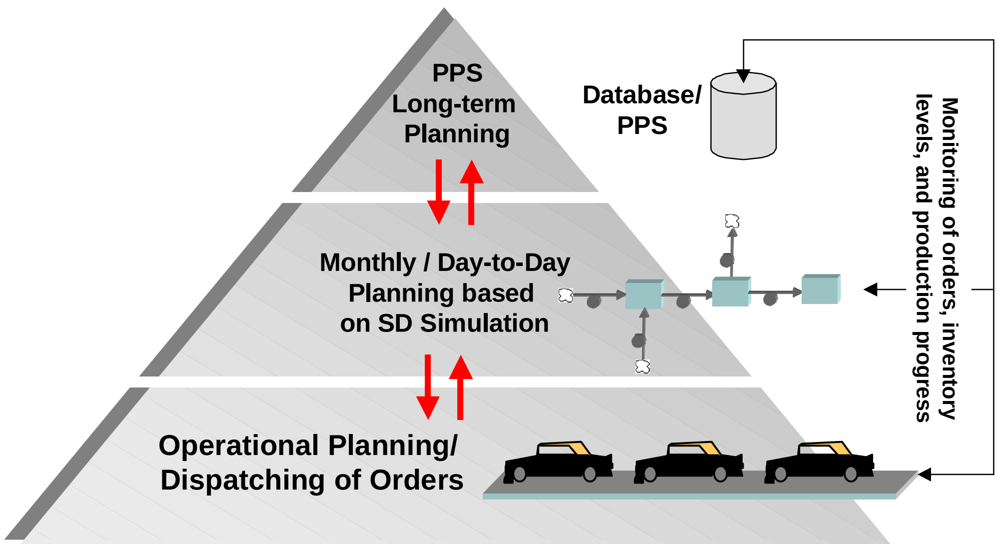

Figure 2: Planning Process and Integration of System Dynamics Modelling

In the next chapter we describe the developed dynamic planning and monitoring tool in detail and show how the production-planning department uses it for production planning and inventory management.

5. System Dynamics model for inventory management

Figure 3 shows a basic Causal Loop Diagram, illustrating the process of production planning and control. As shown in figure 3, three main factors influence the rate at which car bodies flow among the stackers: Next to the operation times (the working time of the process step, e.g. the number of shifts), cycle times and downtimes determine the throughput rate of production. With *downtimes* we mean the time when a machine is broken or the workers cannot work because components are not available, causing production losses. *Cycle time* denotes the time required to process a car body in one workstation. For example, at the plant in Regensburg the cycle time in the assembly shop is about 80 seconds.

In the planning phase the production-planning department sets up a production schedule. It determines the number of produced units per production department (i.e. body shop, paint shop, assembly shop) for a time period of one month. The production schedule also determines the operations times of each production department. The time unit used in the production schedule is shifts. From the production schedule the production-planning department is able to derive the inventory level of the white body resp. the painted body stacker for every shift (*planned inventory level*).

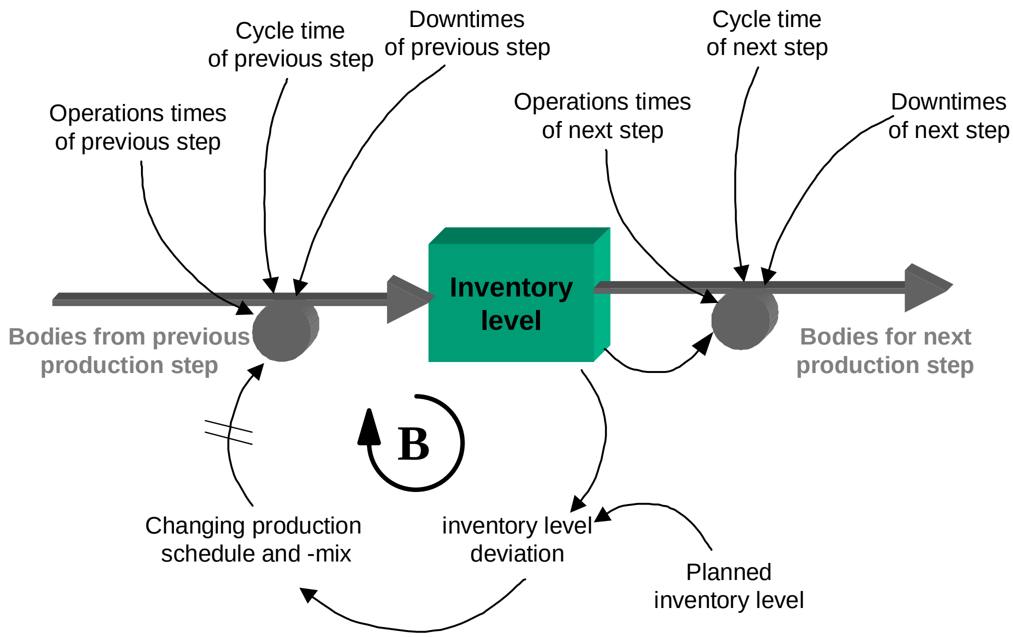

Figure 3: Causal Loop Diagram for Inventory Management

Downtimes and changes in cycle time may reduce the throughput rate, causing deviation of the actual inventory level in the white body resp. painted body stacker to the planned inventory level (*inventory level deviation*). As long as this difference is within acceptable limits, there is no need to change the production schedule. But in many situations changes in the production schedule or production mix are required to meet the long-term production goals (*changing production schedule and –mix*). However, changes in the production schedule have no immediate impact on the inventory level. This is because normally it is impossible to change the production schedule or –mix for the actual running shift. Typically changes in the production schedule or –mix are made for the next week, which leads to a time delay of more than 10 shifts (compare figure 3).

Moreover, changes in the schedule affect the whole manufacturing process and require coordination meetings. In these meetings, members of different departments take part to discuss various options and possible strategies to regain the lost time and production units. In the past these teams often faced difficulties in finding a solution every team member could agree with, because the team members had different understandings and mental models about how the system works.

To support the team's discussion about possible changes in the production schedule we developed an easy-to-use system dynamics tool with the Powersim Constructor (Byrknes, A.-H.). Figure 4 shows the architecture of this tool. The core of the tool is a system dynamics model portraying the flow of the manufactured bodies through the body shop, the paint shop and the assembly shop based on the causal loop diagram in figure 3. Since the details of the production flow in the body, paint and assembly shop are not important for the flow of bodies through the white body resp.

painted body stacker they are modeled as black boxes. Thus the production departments are modeled as rates characterizing the input/output of a production department.

The production-planning department stores the production schedule in a spreadsheet. Via the DDE interface the data is transferred to Powersim Constructor and used to calculate the flows, which determine the input/output of a production department per shift. At the beginning of the simulation the inventory levels (the stocks) of the white body and the painted body stacker are initialized. This initialization is done by reading the actual inventory levels from an online production database system via DDE interface. As output the simulation generates graphs showing the behavior of the inventory levels of the white body and the painted body stacker as estimated for the future.

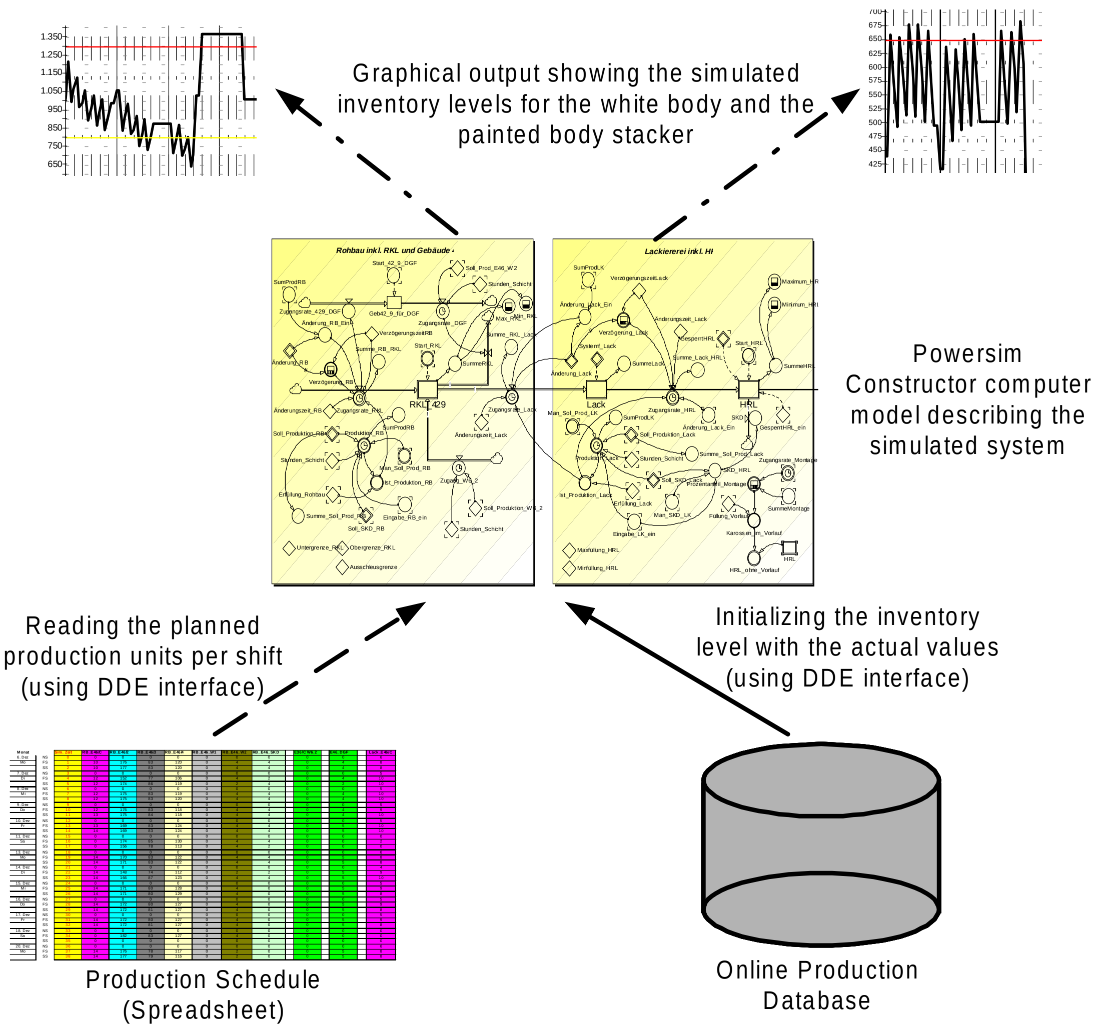

Figure 4: Architecture of the production-planning tool

Using this tool the teams can discuss changes in the production schedule and easily test different options (scenarios) by changing some parameters (e.g. introducing a new shift, changing the production mix, etc.) and simulating the impact of these changes on the inventory levels of the white body and the painted body stacker. Thus the team can easily compare different scenarios and choose the solution, which compensates best the deviation between planned and actual inventory level.

Since the members of the teams discussing changes in the production schedule are not experts in system dynamics and thus are not able to directly manipulate the system dynamics computer model built with Powersim constructor, we decided to develop an easy-to-use user-interface (flight simulator cockpit). This interface allows to change the main parameters needed to develop different production-schedules by using interactive dialog elements, like slider/bar objects, gauge objects, number objects and buttons. The screenshot in figure 5 shows an example of the user-interface of the developed flight simulator cockpit.

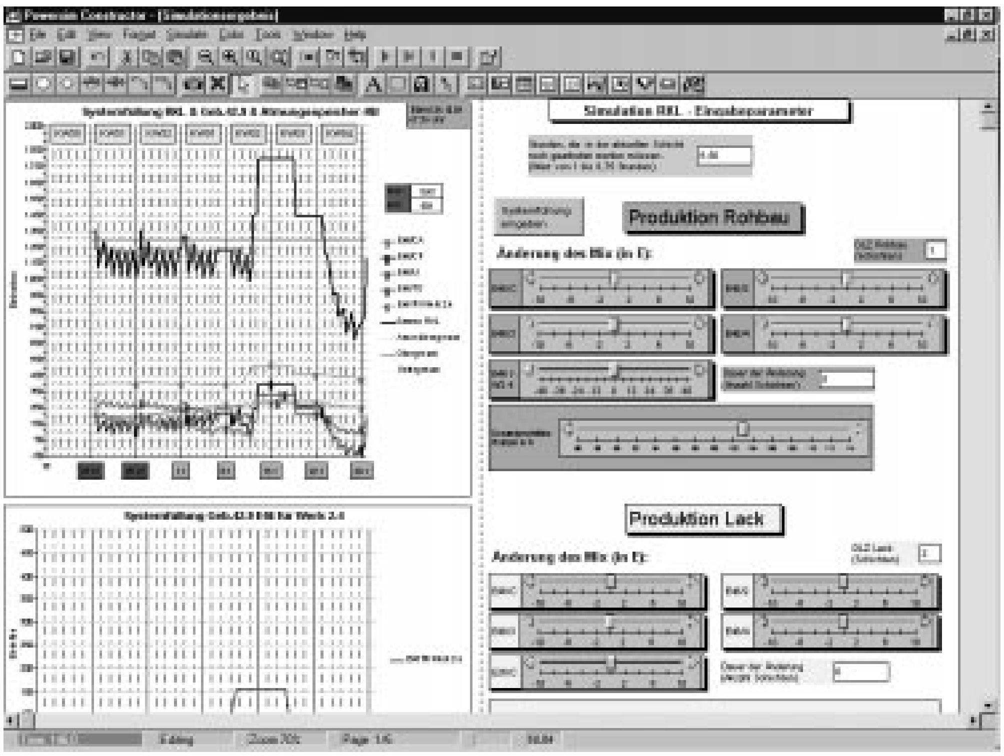

Figure 5: Sample Screenshot of the simulation tool

6. Experiences

The production-planning department at BMW's plant in Regensburg uses the described simulation tool for more than 1½ years. From the experiences made during this time period three main areas of application have emerged: *monthly preview*, *weekly preview* and *daily monitoring and preview.*

The monthly preview is used to hedge against too high or too low inventory levels in the white body resp. painted body stacker due to planning errors in the planning phase. Before we introduced the SD-based tool, the production-planning department planned the monthly production schedule with a spreadsheet. From this spreadsheet the planners derived the levels of the two stackers. Typically this task was done by an expert in planning and in using the spreadsheet. Planning different scenarios was a time consuming process and could be only done by the expert. Thus, only little attention was given to plan different scenarios for the production schedule and many problems arose in the operational phase because no strategy for compensating deviations were preplanned. Nowadays with the developed simulation tool the production-planning department is able to investigate various scenarios in shorter time. Also the scenario planning can be done by non-experts in using the production-planning spreadsheet application, because the user-interface of the simulation tool offers many possibilities for specifying different scenarios. To summarize, the new simulation tool increased the reliability of the monthly production schedule.

The weekly preview is used to plan and discuss different options of compensating a deviation (for example: setting up an additional shift, reducing the planned output of a shift, etc.). Without the simulation tool this process was very difficult and time consuming. The reasons for that were: (1) since many people from different departments with different experiences in production planning were involved, there was no common understanding of how different actions effect the inventory levels. (2) There was no standardized methodology to plan different options. (3) Typically there was not enough time to investigate different options of compensation. With the newly developed simulation tool the process of planning and discussing different options was improved greatly. Nowadays the simulation tool, as a standardized tool, is used during the discussion by projecting the inventory level graphs from the computer directly on a screen on the wall. Thus all involved team members can immediately see the effect of an action on the inventory levels. This improved the common understanding of the system. Beyond that the time for discussing one option of compensation could be shortened significantly and therefore more options can be discussed in the same time.

The actual inventory levels of the white body and the painted body stackers are very important for the production process to work properly. Therefore the production-planning department monitors the inventory levels on a day-to-day basis and provides reports to other production related departments in the plant. In former days, without the usage of the simulation tool, this daily production report showed a static picture of the actual production situation. Therefore, it was difficult to estimate the future development of the stackers and critical situations were often recognized too late. With the help of the new simulation tool the production-planning department extended the daily production report with graphs, showing the estimated development of the inventory levels for the next few days. This report is daily published in the plant's intranet. This allows all departments to anticipate critical situations much earlier and thus, to discuss actions to avoid these critical situations in advance.

7. Conclusions

As shown in this paper the production planning process in car manufacturing is very complex, in order to satisfy customer demands and tastes. Traditional methods of planning, controlling and monitoring the production process are not applicable anymore. Thus new methods are needed. At BMWs plant in Regensburg a system dynamics approach is used. As shown in this paper a simple dynamic simulation tool with an easy-to-use user-interface can significantly improve the production planning process. Although in the beginning of the project some people were skeptical about the simulation, the experiences of the past 1½ years, made at BMWs plant in Regensburg, showed the usefulness of our approach. Today the developed simulation tool is used on a day-to-day basis to support monthly, weekly and daily preview as well as daily monitoring of the performance of the production process.

To emphasize the usefulness of the developed simulation tool we would like to cite the manager of the production-planning department at BMWs plant in Regensburg, who said in an interview:

“The simulation tool used within our department enabled us to increase our production output for more than 2000 units this year. This was achievable, because the simulation tool showed us in advance the possibilities of increasing the production by introducing extra shifts in the production schedule”. Because these 2000 units were needed to satisfy costumer demands, this lead to an increase of net-income of more than 15 million US$.

Since the usefulness of our approach is widely accepted at BMW our future plans are to install the simulation tool at other plants of the BMW Group.[1]

[1]The authors are grateful to the many people at the BMWs Assembly Plant in Regensburg who helped us understanding plant operations including Hans Ebenbichler, Manager of the Production Planning and Control Department, and Thomas Arlt, who did the main work in the development of the concepts for the simulation tool. We also thank Peter Claussen, Manager of the White Body Shop, for his support during the test-phase of the simulation tool.

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