THE DIGITAL FACTORY A NEW COURSE FOR UNIVERSITARY EDUCATION

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Abstract

To enforce innovation and to keep production costs as low as possible automotive industry created the idea of the digital factory. The objective of the digital factory is to simulate and to optimise the complete chain from the design of a vehicle to mass production. This new idea will penetrate gradually in all areas of mechanical and electrical engineering, causing significant changes of organisation, structure and working methods. It will have strong effects on the future sphere of work of students, who study mechanics, mechatronics, productronics and partially computer science. Since globalisation will enforce more and more the digital factory paradigm in the automotive industry, our idea was to develop a common teaching framework for students of Germany and Brazil, which are two countries representing the typical globalisation aspects in automotive industry. Within this framework, students and lecturers are exchanged, and the students are encouraged to not only study in the partner university but also do their practical work in an automotive factory of the foreign country. We developed a new teaching module consisting of the following three components: a set of lectures, which introduce into the modelling and simulation of discrete systems, a series of lectures, which explain the characteristics and objectives of a digital factory, and a laboratory session, during which the students get acquainted with the use of a simulation tool and have to realize a simulation project. In this article we explain the structure and the content of this new module.

Keywords: Digital factory, Simulation, Education, Automotive industry, Global manufacturing.

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1 Introduction

The globalisation of the last decades caused a growing competition pressure for automotive industry. On the one hand the increasing complexity of the vehicles leads to higher costs of development. On the other hand the global competition with worldwide overcapacities produces a strong price competition. This forces the different companies to more innovation that means to faster model changes and to utmost low production costs. The leading automotive companies see in the *digital factory* a forward-looking way to meet these demands [1].

The digital factory is the basis to simulate in detail new products and the associated production lines. The digital factory is the equivalent to the digital or virtual product. Both should be developed simultaneously, to shorten the time to market. It yields an intensive collaboration between product development and production planning. Product and production equipment will only be realized, if simulation shows, that the specified demands on time scheduling, finance and quality are met [2] [3].

Today the term digital factory covers a variety of further aspects. Industry expects that it will lead to secure product and production processes. The digital factory may also include production management or optimisation of current production processes [14]. The simulation data may be even used for programming robots and control systems [7].

This new technology calls for considerable expenditure of hardware, the availability of appropriate software tools and qualified staff but also requires the restructuring of the whole factory. Especially, in order to model the processes of a factory in a realistic way, it is of high importance to implement a global, factory wide data base, which makes available the needed current data at every time.

As automotive industry depends strongly on the suppliers, digital factory technology will only be successful, if manufacturer and suppliers work together within the scope of simultaneous engineering and at the same time pursue the development and planning of a product or a production line.

In all countries, which have an efficient and powerful automotive production at their disposal, the automotive industry has an economically and strategically dominant position. Thus, once established in the automotive area, the digital factory technology will spread out in other areas and dominate the whole mechanical and electromechanical industry, comparable to the actual influence on current research and the development in the electronic area. But "both America and increasingly, Europe are suffering from a shortage of qualified specialists" [4].

In view of a future oriented university education the students should have the possibility to prepare themselves for this coming technology. Hence, the PUCPR (Pontifícia Universidade Católica do Paraná, Brasil) offers in collaboration with the HTWG (Hochschule für Technik, Wirtschaft und Gestaltung, University of Applied Sciences, Konstanz, Germany) a module, which accommodates to this evolution. It consists of the following components:

* a set of lectures, which introduce into the modelling and simulation of discrete systems,
* a series of lectures, which explain the characteristics and objectives of a digital factory, and
* a laboratory session, during which the students get acquainted with the use of a simulation tool and have to realize a simulation project.

The different components will be described in the following.

2 Modelling and Simulation of Discrete Systems

The new digital factory technology will have strong effects on the future sphere of work of the students in the fields of mechanics, mechatronics, productronics and partially also computer science. In order to understand the processes inside a simulation tool, to evaluate the quality of simulation software, to be able to carry out changes or adaptations, or to interpret the results of a simulation study, it is important to know and to understand the algorithms used and the principles of modelling [5] [6].

The lectures about the fundamentals of discrete systems simulation will provide the students with these capabilities by delivering insight into the underlying software technology. They are especially developed for students of technical disciplines which usually are not very familiar with the programming techniques for discrete event systems simulation.

The lectures have the following contents:

1. Introduction and Basic Terminology (2h)
   - different types of simulation
   - typical applications
   - steps in a simulation study
   - systems, models, events, activities and processes

2. Simulation Techniques for Discrete Systems (4h)
   - discrete-event simulation
   - process-interaction approach
   - time driven simulation and other techniques

3. Random Numbers and Random Variate Generation (4h)
   - basics in probability theory and statistics
   - uniformly distributed random numbers
   - testing for randomness
   - random numbers with a desired distribution

4. Statistical Analysis of Simulation Experiments (2h)
   - transient and steady state behaviour
   - estimation of the parameters of a distribution
   - probability of attributes

5. Discrete-Event Simulation of Material Flow in Queueing Networks (6h)
   - graphical description of material flow systems
   - production lines
   - division and confluence of material flow
   - push and pull principle
   - just-in-time strategy
   - random failures
   - inventory systems

6. Software for the Simulation of Discrete Systems (2h)
   - object oriented programming of simulation software
   - eM-Plant, AutoMod, ARENA, others

The aim of this course is to model the discrete aspects of a complex production process with a special focus on stochastic influence factors. With the aid of the simulation techniques presented it is possible to investigate typical performance measures like, for instance, throughput time, availability and utilisation of resources, necessary buffer capacity, or inventory utilisation. By simulating different layout alternatives optimisation with respect to a given criterion may easily be done.

Continuous sub processes like the movement of transport vehicles may be integrated in the discrete model without loss of necessary information. Other aspects of a continuous nature like the behaviour of a single robot system are located on a deeper abstraction level than, e.g., material flow, and are the objectives of specific courses.

3 The Digital Factory

As the first series of lectures teaches the basic knowledge for modelling and simulation of discrete systems, the second first describes, how that knowledge is used in practice. Here we use examples of automotive factories which are located in Brazil as well as in Germany, focussing on globalization problems.

3.1 Planning new production equipment

The second series of lectures first introduces into the sequence to plan new production equipment in automotive industry. It shows that planning is a relatively complex procedure, which needs a lot of time, while the automotive market asks for increasing faster model changes. That results in the fact, that frequently planned deadlines are not respected and the most important mile stone, the SOP (start of production) is by far exceeded. By using simulation a more reliable planning can be achieved and scheduled dates can be followed.

3.2 Realizing a simulation project

Next the lectures explain how a simulation project has to be conducted illustrating the different steps of a simulation study like analysis, modelling, implementation, verification etc. Further some practical examples show, what kind of improvements can be achieved by using simulation and an overview is given about the most important currently available simulation tools and their application areas.

3.3 Industrial application example: Optimisation of a colour sorting storage

To explain how simulation is used in industry, a project, which was realized by automotive industry, is shown. When the body of a car is finished in the body shop, it has to be painted. But the colours of the cars differ. To save cost and manufacturing time it is more effective, when the cars, that will get the same colour, are blocked together, which means are painted one by one. Therefore the cars have to be sorted before entering the paint shop. This is done in the colour sorting storage.

3.4 Case study: Material flow in a body shop of an automotive plant

Next it is demonstrated, how a model of a production line in the body shop of an automotive plant can be built. Starting from the layout of the line the model is setup. The results of the simulation are explained. They give an overview about the capacity of the production line, probable bottle necks and possible improvements.

3.5 Virtual and augmented reality

Frequently it is not easy for non specialists to interpret simulation results. The more complex a model gets the more difficult it is to evaluate the results. An essential support can be given by *3D-Virtual Reality* or *Augmented Reality*. 3D digital reality means, that a three dimensional representation of a product or a production line is generated in life size by computer using simulation data. Big screens up to a size of thirty square meters are today available. The 3D virtual reality presentation gives an excellent support for joint meetings between product development and production planning. Design changes of a product to facilitate production can be discussed in a very early state using a virtual three dimensional representation [13].

Augmented Reality means that 3D information is superimposed into a real environment at real-time. The difference between Augmented Reality and Three Dimensional Virtual Reality is, that 3D information can be directly integrated into digital images of the real world. With the help of the augmented reality virtual, three-dimensional information can be inserted in real-time into digital images of the real world. For example a new, CAD-designed door of a car can be integrated into a digital photo of the real car [15].

3.6 Current situation

Today in many areas of the different automotive companies simulation tools are used to support the development of new products and the planning of new production lines as well as to control and to optimize production. But in most cases these are isolated applications, which means simulation is only used to optimize certain aspects or characteristics of a product or a production line. The application is always confined to a limited application area like the optimization of a conveyor system, the working sequence to install a front window of a vehicle, or the optimal capacity use of robot stations in the body shop [9].

3.7 Digital Factory, definitions

The objective is the virtual realization of the complete product and the associated production equipment. This goal can only be reached with the aid of the digital factory.

The digital factory is the equivalent to the virtual product. Both have to be created tightly interlocked at the same time. Digital factory means the use of digital planning methods during the whole life cycle of a product from product development, planning of production equipment to mass production.

"The Digital Factory is the generic term for a comprehensive network of digital models, methods and tools including the simulation and 3D/VR-visualisation, which are integrated by a general data management. The goal is the complete planning, evaluation and continuous improvement of all essential processes and resources of the factory in relation to the product "[7].

The digital factory includes terms like *Virtual Engineering*, which makes methods and tools available for integrated digital development, testing and management of products and production lines or computer integrated manufacturing *CIM*, which stands for the computer supported integration of the different segments of a production line or the different areas of a factory like production, machine tool scheduling or supply ordering. To build up a digital factory a sequence of preparatory steps are necessary [11].

3.8 Standardization

A unified standard for production equipment has to be defined. Standardized building blocks have to be designed, enabling the automated planning of new production lines by just putting the building blocks together. The detail work is done by the computer. During the first period of industrialization production was automated, during the second planning and partially development will be computerized

All computer based tools as well as all operations of the factory must have access to a factory wide central data base, which contains all up-to-date information from product design, planning production, administration to sales.

The creation of a factory wide data base requires a standardization of the work flow of the factory, so that the data, which are produced during each step of the work flow, immediately can be stored in the central data base. That allows simulation to access the current data of development and planning at any time. The amount and the type of data needed to build this data base have to be defined.

3.9 Work flow management

An extensive reorganisation inside a company is needed. The work flow in the company has to be investigated. Generally, numerous orders of customer specific special cases will be found. A great importance has to be attached to transform these special cases into a standard work flow or to adapt them to fit a standard work flow. Then for each step of a work flow it has to be specified, which data it produces and how this data has to be stored in the central data base.

3.10 Data integration

The administrative and commercial areas have to be integrated with the engineering area. That means a general data flow between these two areas has to be implemented, as the simulation needs administrative and commercial data as well as structural and geometrical data. To achieve this goal special data structures have to be developed to render possible a link between the different areas.

In this way the central data base permanently holds a complete image of the current situation of all activities, which are going on in the company. Each simulation will always have access to the current stock of data and will furnish results, which correspond to the current state of development and planning.

3.11 Teamwork and Simultaneous Engineering

To execute activities in parallel, which are today executed in a sequential manner, helps to save time. To shorten the production planning cycle of the product development and planning must take place in parallel as far as possible. That demands teamwork. All parties involved in developing and producing a new product have to execute simultaneously their work and to lay open their daily work progress any time. An information exchange cannot just be done, when the development of a component is completed. Only by using simultaneous engineering the requirement can be obtained, that all components are also available, when the virtual development of the car body is completed [12].

3.12 Interface problems

The information exchange addresses a vital problem. The structure and the functionality of many tools and the data and data types they need for working are so different in many cases, that information exchange and data conversion are often nearly impossible. One future main task will be to define *open standards*, which define functionality and interfaces [7].

3.13 Collaboration between car manufacturer and supplier

As car industry confines itself to produce the car body, the motor, the power train and to assemble the vehicle, the production depth today is about 20 %. Numerous components have to be developed and produced by suppliers. But the idea of the digital factory asks for the simulation of the whole vehicle and therefore forces the integration of all suppliers. The result is that the current data of the manufacturer have to be available to the suppliers, and the development data of the suppliers have to be accessible by the manufacturer. A virtual team has to be installed, in which the members are locally separated but linked together by a permanent intensive information exchange.

Consequently significant problems arise for the suppliers. On the one hand they have to dispose of the same simulation tools as the car manufacturer, which can force high investments. [9]. On the other hand they have to adapt to a similar organisational structure as the car manufacturer. They have to use similar data structures, to store administrative and geometrical data, to standardize the work flow in their companies and to grant access for the manufacturer to the data, which are generated by each work step [16] [17].

3.14 Challenges

The interconnection by computer networks, which is needed for such a close collaboration, undoubtedly entails some significant problems [12]. Actually nobody knows how the computer networks can be protected with an absolute security against unauthorized people. For instance, how can be inhibited, that a supplier transfers secret data to other car manufacturers, how secret services can be prevented to have access to the data or how to inhibit malicious attacks from outside.

3.15 Structure of the course

If the previous explanations are converted to a set of lectures, they may have the following structure.

1. Automotive Industry (2h)
    - Characteristics
    - Current situation
        * planning a new production line
        * product life cycle

2. Simulation (6h)
    - Definition
    - Sequence of a simulation project
        * analysis
        * modelling
        * implementation
        * verification
        * experimentation
        * validation
    - Discrete event simulation
    - Main mistakes in simulation
    - Application areas
    - Market of simulation tools
    - Small application examples
    - Videos showing simulation result

3. Optimisation of a Colour Sorting Storage (1h)
    - Initial situation
    - Structure of the storage
    - Implemented procedure
    - Optimisation
    - Results

4. Development of a Simulation Model: *Material flow in a body shop of an automotive plant* [2h]
    - Structure and layout of the production line
    - Logical level
    - Simulation results

5. Virtual and augmented reality (3h)
    - Definitions
    - Benefits
    - Video examples

6. Digital Factory (10h)
    - Definitions
    - Principles:

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- Workflow
- Information exchange between engineering and financial area
- Workflow management
- Data integration
- Teamwork and simultaneous engineering
- Automation of planning
- Interface problems
- Collaboration manufacturer /furnisher
- Economical aspects
- Current situation
- Challenge, questions and threats

7. Conclusion

After the students have got an insight in this new technology, it is appropriate to show, how the simulation of a new product or a new production line is done.

Therefore after the lectures a laboratory session is offered.

4 Laboratory Session

In order to make visible the interdependencies between simulation and reality and to make possible the validation of the model a concrete system running in the laboratory has to be modelled. Technical oriented students have to model a realistic material flow problem which is available in reality at the PUCPR (fig.1).

If there are enough students of business administration in the course to establish a separate working group, the difference of typical material flow problems and business processes can be pointed out. Instead of simulating a material flow problem, they have to simulate a typical business process.

4.1 The task for students of technical disciplines

The system consists of

* a distribution station
* a test station
* a production station and
* a stock of processed parts (fig. 1)

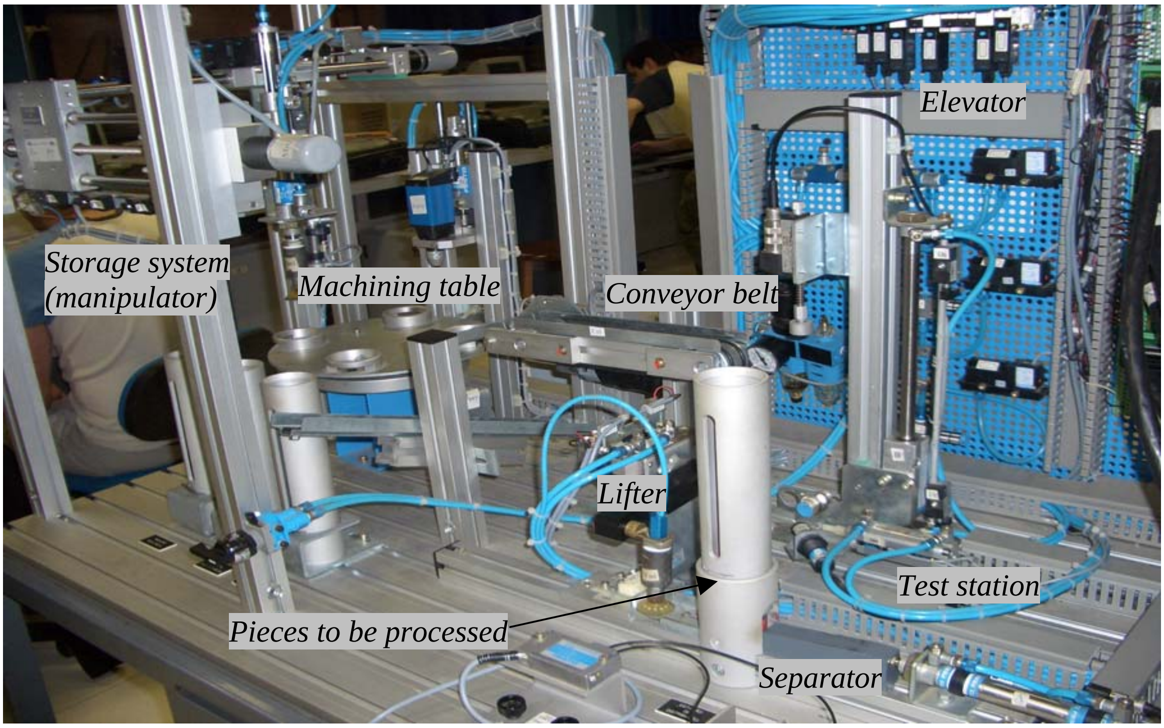

Fig. 1 Laboratory model of a production line

For the simulation of the system the simulation software eM-Plant is used, which is one of the most established software tools in the automotive industry. Several licences are available at the PUCPR.

At the beginning the goals of the simulation have to be specified, that means which results should be achieved. The structure of the simulation model is implemented graphically by using a set of available symbols, called building blocks. Special characteristics can be specified using the programming languages called SimTalk. SimTalk as well as the whole simulation tool is object oriented. The concept of the language looks like Visual Basic.

A top down procedure will be used. First the students have to build a rough logical model of the system (fig. 2) and then the stations have to be specified in detail. The students have to define the degree of specification. Set up, recovery, cycle and processing times can be measured at the hardware model and entered in the simulation. Then the model has to be validated. The behaviour of the real system and the model has to be compared to judge the quality of the simulation. If needed improvements have to be made and perhaps more details introduced. During validation students have to learn to interpret the results of the simulation runs. If the model has been validated, the students can start to experiment with the model. The simulation parameters will be changed systematically, e.g. to check, how the throughput of the production line can be improved by using more powerfull components like a faster storage system.

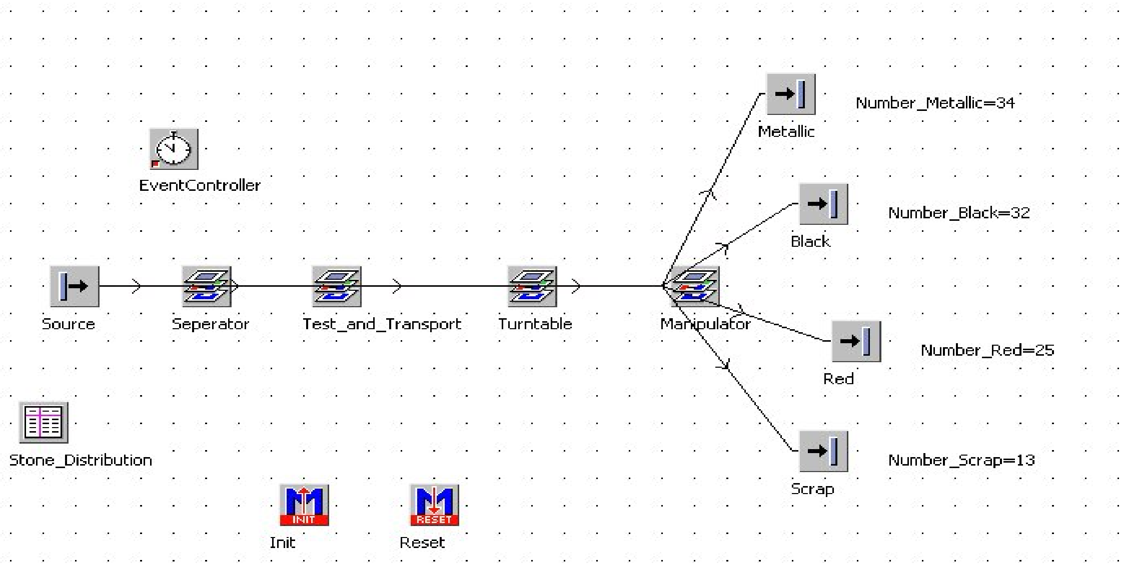

Fig. 2 Simulation model of the production line, overview

The students are divided into groups of two. At the end of the laboratory session every group has to present its model. According to experience, the models will be different, demonstrating that there usually exist several possible models of a production situation.

4.2 The task for business administration students

Students, who are studying business administration, have to simulate the business process “Order Management by a Wholesaler” (fig 3). A preliminary discussion shows that the simulation software eM-Plant is not very well adapted to simulate these types of problems, thus other modelling and simulation tools like ARIS [18] should be used. In such systems the process character of work flow is fucussed more forcefully.

In the example the sales department of a wholesaler receives an order of a client. The sales department sends a demand to the warehouse. If the demanded article is in stock, then the demand is satisfied instantaneously, otherwise the demand is stored as unsatisfied and a report is sent to the sales department. The sales department sends a repeat order to the purchasing department, which forwards it to the producer. When the reordered article arrives at the warehouse then it is forwarded to the shipping department and then shipped to the client.

Typical performance measures of this system are, for instance, the mean time until an ordered article arrives at the client, the percentage of orders which cannot be satisfied instantaneously, or the utilization of the departments in the wholesaler.

5 Conclusion

During the next decade the idea of the digital factory will penetrate gradually into all areas of mechanical and electrical engineering and cause significant changes of organisation, structure, and working methods. It will fundamentally restructure the collaboration between the different departments of a factory and the various subcontractors. Modern information technology makes even global acting componies capable of integrating their world wide

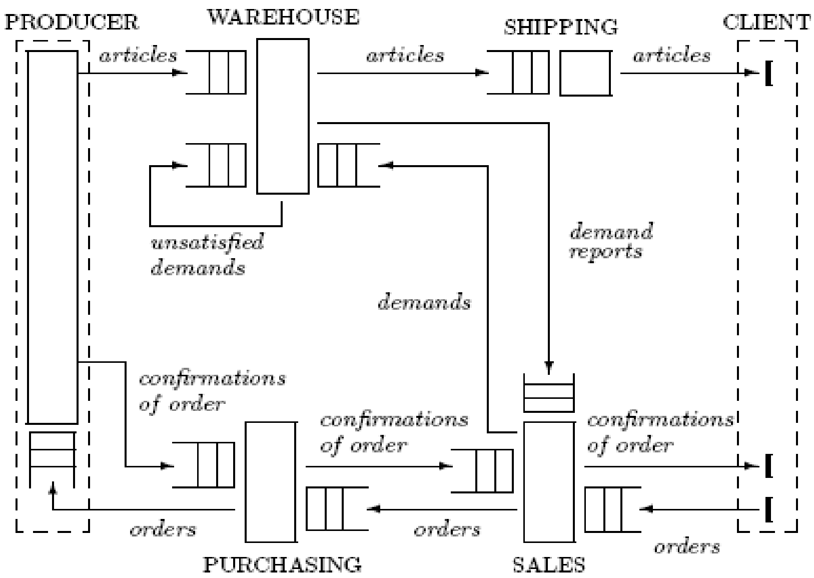

Fig. 3 Business process Order Management by a Wholesaler

activities, reconciling the technical and the business processes. The series of lectures and laboratory sessions described allow interested students from two distinguished countries representing the typical global aspects of automotive industry to prepare for the futures changes.

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