ABSTRACT
The finiteness of oil resources are an elementary motivation for the research, development and production of electric drives. A lot of electric drive products with innovative technologies are developed. The challenge of the industrial production and suppliers is to produce these new technology products beside the approved products like fuel based drives, because the demand of e-drive products will not replace the existing products. New processes of development, supply and production control have to be integrated into existing process workflows. BPMN (Business Process Modelling Notation) supports graphical process modelling for business processes and workflows. The approach is to model new product development and production control processes. Therefore information of existing CAD (Computer Aided Design) and CAM (Computer Aided Manufacturing) systems are used. The research tool PROCAS (Process Optimization, Control, Analysis and Simulation) was developed to make process modelling with BPMN and integrate CAD and CAM information into the process models. A case study with PROCAS shows an example how new processes of electric drive development and production can be integrated into existing process models.

KEY WORDS
Model development, process control, BPMN, product development, production control, electric drives, CAD

1. Introduction

1.1 Problem and Challenge

The shortage of oil resources leads the development to find alternative drive systems. Rising oil prices causes direct cost of mobility [1]. Mobility with fuel powered drives becomes more expensive in future. The demand of alternative drives for vehicles is discussed by automotive producers, politicians and customers. Electric vehicles are one of the alternatives. Another motivation to produce electric vehicles is to reduce the atmospheric noise especially in big cities. The smoke in big cities like Beijing damages the health and wellness of the population. The air pollution caused by the traffic could be eliminated with electric vehicles. The climate change is a dominant discussion topic in publicity. The emission of CO₂ of vehicles could be avoided by electric vehicles depending of the power generation. Alternative power generation from wind, water and sun energy should be much more used to supply the demand of power. In future the utilization of electric vehicles will be in cities and for short distances. New types of cars are already produced by several automotive manufactures. For example in Figure 1 is a vehicle with electric drive based on hydrogen fuel cell shown.

Figure 1: Vehicle with electric drive based on hydrogen fuel cell [2]

Like in [2] described hydrogen fuel cells produce electric power with high efficiency. Essential advantage of hydrogen fuel cells compared to batteries is that currently the chemical energy storage in liquid or gaseous form has a higher energy density. Difficulty of hydrogen operation is the storage in the vehicle.

One research challenge is how production of electric vehicles can be done. The existing production plants are manufacturing fuel powered vehicles. The demand of electric vehicles will not replace the fuel powered vehicles. So the variants of vehicle types will rising up. This means more complexity in production. Different kinds of product variants have to be built in the same production lines. In the automated production the
robots have to do different kind of production workflows. The stocks have to store more various products. Another research motivation is how production and supply capacities have to be dimensioned for electric vehicles. Automotive production has to be flexible in producing flexible quantities of fuel powered and electric vehicles. It depends on the success of the new mobility technologies how the market of electric vehicles crows. The dynamic changes of demand efforts a good capacity planning for the production and the supply chain.

Next research motivation is how the production of electric vehicles can be controlled. Production and supply chain process workflows have to work well. Therefore process models are developed for simulation and optimization. Various production process models and supply chain process models are examined. The workflow between the production processes and the supply processes are discussed.

The research motivation is how to find out good production and supply chain processes for the production of electric vehicles. Therefore construction data from CAD systems from the development is used to determine which kinds of components are necessary for producing the electric drives.

The manufacturing information of CAM systems is employed. New manufacturing workflows for the combined production of fuel powered and electric drives have to be modelled, simulated and optimized. Automotive production industry starts to produce electric vehicles in cooperation with other automotive manufacturer. The research challenge is who the construction between automotive manufacturers fits together. All the affected CAD development systems have to change construction data that the integration of the components can be designed and simulated. A further challenge is that the new electric technology will have a lot of technical improvements because a lot of research is done for optimizing the technique. The problem for the production is that the technological changes have to be done in a running production.

1.2 Objective

The research objective is to make an overview of the process workflow of the business processes, marketing, product development, production and supply chain. The overview of the process workflows gives a possibility to illustrate how development and production planning and control departments work together.

New process workflows for electric car production have to be integrated into the existing process workflows. Existing and new process models have to be simulated to examine if they work well and if there are any bottlenecks. After simulation the process workflows have to be optimized. One objective of the optimization is to reduce the complexity of the workflows.

The objective of optimization is to avoid process wait times so that the production lead time can be reduced. A further optimization purpose is to reduce process steps so that the production can be done with less technical equipment like robots and with fewer employees to reduce the production cost.

The development of PROCAS supports to model the development and production control processes in BPMN. Process workflows have to be designed graphically to describe and get a better understanding about the workflows. Additionally the BPMN process models visualize the interaction between the workflows of the development, suppliers, and production plants.

A further purpose is the development of an interface to CAD systems to get information about the parts of fuel powered and electrical devices. Additionally the CAD data of assemblies and modules can be exported to PROCAS.

Additionally an interface to CAM systems has to be created. CAM systems deliver data about production steps and operating procedures. For example procedures of fixing car bodies by robots or the assembly of electric devices can be exported from CAM systems.

A further task is to examine the supply and demand of electric components during the production control. During the production control the filling of storages has to be controlled. Upcoming bottlenecks of the component delivery have to be visualized in time so that activities can be made to avoid the problem.

The KPIs (Key Point Indicators) supply lead time, availability and quality are measured. With these indicators the workflows can be improved. Shorter lead times help to produce the product in less time.

The availability of parts, assembly and modules are essential for short production lead time. A good availability of the supply chain and production results in a reliable completion of the products for the retailers and customer.

1.3 Outline

In chapter 2 a state of the art about fuel powered and electrical drives is given. Chapter 3 introduces BPMN 2.0 modelling Process models of product development and production control are shown in chapter 4 and 5. The case study in chapter 6 is about process modelling and process integration of e-drive production in an existing production process. Finally the paper ends with the conclusion in chapter 7.
2. Previous Work

2.1 Electric Drives

In article [3] the Automakers’ powertrain options for hybrid and electric vehicles are shown. The article describes the evolution of vehicle electrification from various forms of hybrid electric vehicles such as micro, mild-medium and full hybrid vehicles to plug-in hybrid electric vehicles and battery electric vehicles and from fuel cell hydrogen electric vehicles to multi-purpose electrified traction platforms and architectures. In article [4] an economic and environmental comparison of conventional and alternative vehicle options is made. The evaluation is based on actual cost data, life cycle indicators for vehicle production and utilization stages. The vehicles analyzed include conventional gasoline vehicles, hybrid vehicles, electric vehicles hydrogen fuel cell vehicles, hydrogen internal combustion vehicles and ammonia-fuelled vehicles.

In article [5] an overview about fuel cell electric vehicles, battery electric vehicles and their impact of energy storage technologies is given. The article focuses on energy storage technologies in cell electric vehicles and battery electric vehicles. It discusses the latest vehicle projects like the GM HydroGen 4 and the Chevrolet Volt as well as the respective VOLTEC powertrain system.

2.2 BPMN Process Modelling

The workshop series of the international BPMN workshop 2010 provides a forum for academics and practitioners [6]. The second workshop 2010 in Potsdam Germany contains among others the papers “BPEL vs. BPMN 2.0: Should You Care? [7] and “An Overview of BPMN 2.0 and Its Potential Use [8].

In the article [9] the application of interoperability requirement specification and verification to collaborative processes in industry is described. In this article is pointed that interoperability is becoming a crucial issue for the industry and a lack of interoperability can be seen as an important barrier to collaborative work in inter-enterprise and intra-enterprise collaborative processes. The research proposes is to use formal verification techniques to detect different types of interoperability problems. In article [10] modelling, simulation and fuzzy decision making of distributed production control and supply chain methodologies is shown. The challenge of distributed production plants and global supply chains are explained. The proposal of the paper is to design distributed production and global supply chain processes by BPMN.

2.3 Product Development

The article [11] describes a framework for computer-aided conceptual design and its application to system architecting of mechatronics products. The statement of the paper is that conceptual design of modern products has become complex due to an increasing number of subsystems and components. The paper proposes a product modelling framework and a CAD system for conceptual design of complex products.

Article [12] of the E-CAD workshop series in Stuttgart, Germany 2010 introduces tools for process modelling and optimization of production planning and control systems with electric CAD application examples.

2.4 Production Control

One of current research topic in production modelling is agent-based modeling. In paper “Agent-based modeling and simulation of an automatic manufacturing execution system” [13] the “concept of order and resource agents” is explained. “The usefulness of agent-based modeling and simulation for distributed manufacturing-execution systems (MES) are presented”. In article [14] it is predicate that Computer-Aided Manufacturing (CAM) occupies an increasingly important role in engineering CAM offers new possibilities and improves designer and manufacturer productivity. The paper presents machining of free-form surfaces on a 3-axis NC machine tool. In paper “Agent-based modeling and simulation of an automatic manufacturing execution system” [15] the “concept of order and resource agents” is explained. “The usefulness of agent-based modeling and simulation for distributed manufacturing-execution systems (MES) are presented”. In paper “Data driven production modeling and simulate ion of complex automobile general assembly plant” [16] a “data driven simulation methodology to automatically model a production system is developed. The model can be rapidly modified corresponding to dynamic requirements and real time information”. A current approach in planning production is the usage of CAD tools. 3-D CAD models of manufacturing devices like robots are created. A further novel research topic is the “simultaneous optimal selection of design and manufacturing tolerances with alternative manufacturing processes” which is represented in [17].

A novel modelling approach for concurrent product engineering and assembly sequence planning is presented in [18]. “The main objective of this research is to integrate assembly process engineering information in the early phases of the product development process.

77
3. State of the Art Development of Fuel Powered and Electric Drives

3.1 Overview of Drive Systems, Energy Storage and Transformer Method of Vehicles

In these chapter state of the art concepts of thermal drives, alternative fuels and electric drives are introduced. An overview of possible drive systems are shown in Figure 2:

Figure 2: Overview of drive systems, energy storage and energy transformer method for vehicles [2]

In this figure the energy sources wind, water and sun are shown. Energy can be stored by electric and thermal energy storage possibilities. Energy converter concepts like fuel cell and generator are illustrated. Additionally there is an overview given about electric motor and thermal power machine types.

3.2 Thermal Drives Concepts

3.2.1 Principle Concept of a Combustion Motor System

Principle modules of a combustion motor system are illustrated in Figure 3:

Figure 3: Principle modules of a combustion motor [2]

The basic modules of a combustion engines are
1. Combustion engine
2. Fuel injection system
3. Valve control system
4. Water pump
5. Charging system

3.2.2 Principle Concept of a CNG (Compressed Natural Gas) Patrol Dual System

In Figure 4 are the additional system modules of an CNG fuel dual mode displayed.

Figure 4: Additional system modules of a CNG fuel dual mode [2]

3.3 Electric Drives Concepts

As in [2] described, all concepts of electro motors are based on electric generated electro magnetic fields. The electromagnetic fields generate magnetic power by induction. The magnetic field remains in equal position for direct current motors. Three-phase motors have a rotating magnetic field. Depending on the power, torque and efficiency factors different kind of electric motors are used for automotive drives.

Table 1

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Power [KW]</th>
<th>Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct current motors (n ≤ 7000 rpm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jinan Baoya BY5000EV-1A</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td>Alternate current asynchron motors (n ≤ 14000 rpm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jinan Baoya BY6500EV-1</td>
<td>6,5</td>
<td>120</td>
</tr>
<tr>
<td>Alternate current synchon motors (n ≤ 14000 rpm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renault Kangoo Z.E.</td>
<td>44</td>
<td>226</td>
</tr>
<tr>
<td>Peugeot iOn</td>
<td>47</td>
<td>180</td>
</tr>
<tr>
<td>Mercedes Benz Vito E-Cell</td>
<td>60</td>
<td>280</td>
</tr>
<tr>
<td>Tesla Roadster Sport</td>
<td>215</td>
<td>400</td>
</tr>
<tr>
<td>Shelby Aero EV</td>
<td>750</td>
<td>1088</td>
</tr>
</tbody>
</table>
3.4 Hybrid Drive Systems

As in [19] described the operation of an electric hybrid vehicle is determined by the operation strategy. It depends on the optimization intention. Intentions can for example be emission or petrol reduction. The operation strategy controls the distribution of the required torque onto the combustion and the electric motor. Intention is to run the combustion motor in a favourable operation point.

3.4.1 Concept of Serial Hybrids

Modules of a serial hybrid car are shown in Figure 5:

3.4.2 Concept of Parallel and Mixed Hybrids

There are different kinds of concepts for vehicle drives with combustion and electric motors. The typical classification of hybrid concepts depend of the relative percentage of the electric power of the complete drive power.

As in [2] defined the relative percentage can be calculated by equation (1):

\[ \text{Rel.\%} = \frac{\text{Electric Power}}{\text{Electric Power} + \text{Combustion Power}} \]  

The classification can also be done by the absolute electric drive power \( P_{EM} \). Therefore following categories of parallel and mixed hybrids in Table 2 exists:

<table>
<thead>
<tr>
<th>Hybrid Categories</th>
<th>Electric Drive Power ( P_{EM} )</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro Hybrid</td>
<td>&lt; 6 kW</td>
<td>Electric motor is used to start the combustion motor</td>
</tr>
<tr>
<td>Mild Hybrid</td>
<td>6-20 kW</td>
<td>Electric motor supports the combustion motor during acceleration. The brake power is transformed in electric power and stored in the battery</td>
</tr>
<tr>
<td>Full Hybrid</td>
<td>&gt; 40 kW</td>
<td>One or more drive electric motors generate the torque combined with the combustion motor</td>
</tr>
</tbody>
</table>

3.4.3 Concept Full Hybrid – Two-Mode Hybrid

In [2] is a Two Mode Hybrid concept described. The concept consists of two electric motors- The electric motors are integrated in the gear of the combustion motor. The concept is shown in in Figure 6:

In the following Figure 7 Two Mode Active Hybrid gear from [2] is illustrated:
4. Process Modelling with BPMN

As in [20] described BPMN is a language for construction business process models. It is the most widely adopted, by modelers and tool vendors alike. The usage of BPMN is divided in [20] in three levels

- BPMN Level 1, or descriptive modelling, is documenting the process flow.
- BPMN Level 2, or analytical modelling, leverages the expressive power of the complete notation to describe the activity flow precisely,
- BPMN Level 3, or executable modelling, adds detail in the XML underneath the shapes and symbols.

4.1 Level 1: Descriptive BPMN

BPMN level 1 contains a huge amount of graphical modeling symbols. The modeling palette is described in [20]. Following steps are recommended:

Step 1: Define process scope
Step 2: Create the top level diagram for the happy path
Step 3: Add top-level exception paths
Step 4: Expand sub processes to show detail at child level
Step 5: Add intermediate message flows to external pools

4.2 Level 2: Analytical BPMN

As in [20] described analytical BPMN provides precise execution semantics. The level 2 method expands the steps of level 1 with the following further steps:

Step 6: Refine branch/merge notation
Step 7: Refine for channel-dependent start
Step 8: Refine for iterative behavior
Refine iterative behaviour using repeating activities or multi-instance pools.
Step 9: Refine exception handling patterns

4.3 Level 3: Executable BPMN

BPMN 2.0 Level 4 modelling is an XML language describing an executable process. Its focus is the XML details underneath [20]. Executable modelling in BPMN 2.0 is made by populating XML metadata in the model. After creating the flow diagram the executable detail is entered in the execution-related properties of each activity, gateway, event and data flows between them. Executable BPMN has process data [20]. A data object signifies a process variable defined by an XML schema. A data association connects the data object to the flow elements. In Figure 8 is an example of a process flow with data objects shown:

Automated tasks in BPMN are represented as services in BPMN (see [20]). A service reference names a callable service in BPMN. Each service requires an interface. The interface defines a set of operations which are provided by the service. Each operation references a set of messages. Input messages are used to invoke the service. In Figure 9: Example services and messages Figure 9 is an example of services and messages shown.

In BPMN 2.0 specification of executable human tasks can be made (see [20]). One type of human task is called user task where the task is performed by a computer interface. The result of the computer input is sent back to the process engine. A human workflow example is shown in In Figure 10.

The retailer receives the order of the customer. He enters the order data and target date into the order system. The manufacturer production planer gets the order with the order information and the target date. He plans the order for production. After the production the product is delivered to the retailer. The retailer gets the delivery date and the product for the customer.
5. Process Model of Product Development

A BPMN process model for product development is shown in Figure 11. A process request message with the product specification is sent. The first human task starts and makes the variant construction of components by CAD. The data object product specification is an input which describes for example product forms, sizes, functionalities, propositions. The designed component construction is the input for the human task construction of component assemblies and modules. This human task joins the components to assemblies and modules. The next human task integrates the modules into the product construction. A service task follows which analyses and simulates the product construction. If the result delivers any errors the previous tasks were informed and corrected. Finally the data objects product construction and analysis results are sent back as response message.

6. Process Model of Production Control

The second pool of Figure 11 shows the BPMN process model of a production control. The component, assembly, module and product construction are sent to the production control workflow. First human task is the production planning. Production processes and production facilities like robots and assembly lines are planned. Therefore CAM systems are used. Order requests are received by the distributors. The human task order sequencing creates the production order sequence. Next service task calculate component demands and sends a message request to the suppliers. After receiving the components the next task produce the product. Next task checks the product quality. If there are any quality defects the production are informed and have to rework the product. Finally the produced product is returned to the distributor.

7. Case Study

Figure 11: Process Modell of Product Development and Production Control

Figure 12: Process Modelling for Development and Production for Hybrid Drives with PROCAS
Figure 12 shows process modelling for the development and production of fuel powered and electric devices by PROCAS. The modelled BPMN process models are shown in the left window.

The BPMN data objects of the development are CAD constructions. A hybrid gear system is shown in the second window. The production control processes are BPMN data objects with CAM data. A robot assembly line is displayed in the right frame. The concept of PROCAS is to model and simulate BPMN process workflows. PROCAS analyses the integration of new process models of electric drive production into existing production processes. Effects of variance increase by electric and fuel based drives are analyzed. The complexity of production processes is evaluated. Bottlenecks of production process are found. The efficiency of various production process models is analysed. Consequences of construction changes of drive systems on production processes are estimated.

8. Conclusion

The finiteness of oil resources leads the development to find alternative drive systems like electric drives. The problem is about the rising complexity of product types. The paper gives a short state of the art about development of fuel powered and electric drive vehicles. The approach is the usage of BPMN. With BPMN process models of product development and production control are modelled. The paper gives a solution how dependencies and interaction between product development and production control can be modelled. The developed software PROCAS supports the integration of new process models caused by new product technology like hybrid or electric drives. The case study illustrates a solution how BPMN processes, CAD and CAM data can be used to understand process workflows of product development and production control.

References