AN INFORMATION MODEL FOR INTEGRATED PRODUCTION SCHEDULING AND TRANSPORTATION PLANNING

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ABSTRACT

Frequent changes in production programs of vehicle manufacturers cause fluctuating transport volumes. This leads to inefficient transportation processes because the two planning domains are not well coordinated. Consequently, transport capacities are poorly utilized and extra transports have to be scheduled. We have identified that well-structured, efficient and transparent planning processes are a key factor for improving the integration between production and transportation planning. Furthermore, information should be up-to-date and easily accessible. Two approaches for a better integration are proposed in this paper: First, we present concepts for the continuous adjustment of logistics to changing production programs. Second, we describe concepts for adjusting production sequences to logistics. Both approaches use a central information platform named Virtual Scheduling and Transportation Model (VSTM) as a basis. This model can be accessed by all relevant planning domains and serves as a common information basis, thus improving data quality.

Keywords: production scheduling, transportation planning, modelling, data quality

1. THE POTENTIALS AND OBSTACLES OF INTEGRATED PRODUCTION SCHEDULING AND TRANSPORTATION PLANNING

In an international setting, procurement and distribution networks expand globally. The automotive industry, which is the target industry of this study, uses widely spread supply and distribution networks.

Parts and materials are sourced from all around the world to make use of specialized suppliers and exploit cost efficiencies. The increasing concentration on core competences of vehicle manufacturers has lead to a high number of value creation partners that have to be coordinated and to high transport volumes that are shipped between plants. Customers are also located all around the world and finished vehicles are often shipped over long distances.

The ambitions of vehicle manufacturers to suit their customers' needs have lead to a high level of product customization and short product life cycles. Consequently, a growing number of product types and models have to be dealt with. This brings forth frequent changes in production programs, resulting in fluctuating transport volumes on the one hand and lower transportation lots on the other hand.

In order to keep transportation and related logistics costs at a low level, production and transportation should be coordinated. A lack of coordination between the two areas of planning causes

- disturbances in the short term horizon,
- low utilisation of transportation capacities,
- scheduling of extra transports,
- cancellation of transports at short notice, and
- increasing inventories.

If production scheduling and transportation planning are not integrated, the demand for transportation is difficult to estimate. Therefore shipments are often scheduled on short notice when the demand for transport becomes clear. With groupage transports for instance, suppliers decide for themselves when they place a shipment. Logistics service providers respond to an ABC or ABD scheme, day A being the day they are notified, day B the day they pick up the shipment, and day C the day they deliver the shipment. This procedure not only causes low transparency for the vehicle manufacturer, it also gives logistics service providers little time to react thus limiting their potential to exploit synergies. Pre-scheduled transport capacities are either not used efficiently if volumes are lower than expected or extra transports have to be arranged to cope with transport volumes that are larger than expected. A common reaction of vehicle manufacturers is to decouple production and transportation with buffer stocks. Inventory is built up until an efficient transport can be realized. While the balancing of inventory and transportation cost is vital to efficient logistics, in some cases both costs can be cut if for example vehicles for the same destination are produced within a short time period. Instead of waiting until eight vehicles for the same destination have been produced, the vehicles could be scheduled for production according to their ship-to location.

Other transportation concepts than direct transports and groupage transports are difficult to implement if little forecast information is available. Milk-runs and different regular services need to be planned ahead in order to ensure a smooth run and good utilization. Moreover, the use of road instead of rail transport is promoted, because of the requested flexibility and short response times. This conflicts with economic and ecological objectives as rail transports are often associated with lower transportation cost and less environmental impact.

Yet, despite of potential savings through integrated planning, logistics is often considered secondary to production planning whereby production is planned, and logistics has to cope with the inefficiencies caused by these decisions. Ertogral et al. (2007) show that when transportation is considered explicitly, production and inventory decisions are affected. Hence, transportation should be balanced with production decisions in order to achieve a better result. Even though it is recommended that companies can realize significant cost savings by integrating planning procedures (Chen 2004), most planners still tend to assume that production takes priority, because of the higher cost proportion. Thus they do not integrate decisions to optimize production and logistics overall.

The European research project InTerTrans meets the abovementioned challenges. It aims at the development of practical and marketable solutions in production scheduling and transportation planning and seeks to develop integrated planning processes and planning methods that allow the inclusion of transportation-related constraints in production planning and scheduling.

2. TOWARDS INTEGRATED PLANNING

2.1. Production scheduling in the automotive industry

Production scheduling takes place in three planning horizons (Boysen et al. 2006). In the long run, the total amount of the goods to be produced in a certain time period is determined through sales planning. Production program planning covers medium time ranges. Scheduling determines the production sequence in short planning horizons.

Scheduling of production orders is a very complex research field. It is characterised by the trade off between a multitude of restrictions and the objective of cost-efficient and on-time order fulfilment (Boysen et al. 2007). Often, high capacity utilisation is a superior goal to ensure the profitability of the capital investments made. In mixed-model assembly lines, the work progress in one cycle is limited. Therefore, it is necessary to combine tasks with higher and lower durations in order to achieve a production process with minimum idle times. After the balancing of the production line production and assembly requirements restrict the number of viable production sequences ensuring that no work station is overloaded. A production sequence respecting restrictions and pursuing objectives is created by applying sequencing algorithms.

Sequencing algorithms can be categorized into level-scheduling, mixed-model-sequencing and car-sequencing approaches. In level-scheduling, the objective is to create a smooth production flow and to minimize disruptions. Mixed-model approaches aim at reducing sequence-dependent work overload based on a detailed scheduling which explicitly takes operation times, worker movements, and station borders into account. Car-sequencing algorithms have the same objective but try to simplify these restrictions by formulating a set of sequencing rules of type $H_o{:}N_o$. These rules postulate that among N subsequent sequence positions at most H occurrences of a certain option o are allowed (Boysen et al. 2006).

$H_o{:}N_o$ rules are a commonly used method for determining production sequences in the automotive industry. Many vehicle manufacturers formulate a large number of requirements taking production and assembly restrictions into account. Logistics requirements have not yet been considered in this process. Despite the high number of already existing rules, studies in the InTerTrans project have shown that room for integrating logistics requirements still exists (Hermes et al. 2009; Zesch et al. 2009).

Scholz-Reiter et al. (2009) also recognize the need for a better coordination of production scheduling and transportation planning. They favour a two stage approach. On the long run, transport relevant targets are made available to production planners (e.g. capacity), who in turn try to realize these targets and create a production sequence that also suits transport requirements. In the short run, information about disruptions in the logistics network (e.g. delays) are used to modify the production sequence and adjust it to new planning parameters.

2.2. ILIPT and the Virtual Order Bank

The aim of the European research project ILIPT was to define, validate and operationalise processes, structures and networks to fit the demand of a build-to-order production in the automotive industry (Parry and Graves 2008). According to Holweg and Pil (2001), one of the major requirements of a build-to-order environment are flexible processes. To support such flexible processes with IT solutions, the concept of a virtual order bank (VOB) was developed (Parry and Graves 2008). The VOB represents a system for collaborative capacity and order management. Capacity data of vehicle manufacturers and suppliers is stored in the VOB by the definition of available capacity buckets. The order management functionality then books customer orders on the defined capacity buckets. An exact determination of delivery dates and the selection of suitable production sites due to the available information increases transparency.

The described VSTM picks up the initial idea of the VOB, a holistic information model. As described in the following chapter, the VSTM currently focuses on the planning and execution domain of the vehicle manufacturer. In contrast to the VOB approach, the VSTM includes a functionality to determine an exact production sequence even taking logistic requirements into account. Therefore logistic capacity information is also part of the VSTM.

2.3. Transportation planning

The planning of transportation networks can be divided into two planning horizons. For longer periods transport network structures are determined through demand forecasts based on sales planning and settled in frame contracts with logistics service providers. The redesign of these structures takes place about every one to two years. Because of the dynamic business environment, these structures can become inefficient within a short time. This occurs for instance when shifting volumes of product flows diverge from the capacities planned earlier. A large number of models, modelling methods and software have been designed to support network design decisions (Beamon 1998).

In a short time horizon, logistics service providers are informed about changes of transport volumes and can react accordingly. They schedule transportation orders and plan tours for their vehicles. A number of algorithms have been proposed to solve the idealized vehicle routing problem (VRP) (Bankhofer et al. 2006). Buchholz and Clausen (2009) discuss solution approaches for practical problems and criticize, that idealized VRP fail to cover important industrial aspects whereas software applications tend to use out-dated algorithms. Moreover, the optimization potential is limited to adjustments within the given transport network structures and the short time span between notification and execution of the transport leaves little room for implementing measures. As coordination between order scheduling and short-term transportation planning does usually not take place, the use of road haulage with only low proportions of rail and sea transport is required in order to guarantee flexibility. This leads usually to higher environmental damage and elevated transport costs.

Consequently, a better visibility of production scheduling decisions is the basis for improved transportation planning. State-of-the art planning software that can cope with real-life transportation requirements is then needed to continuously optimize transportation networks (Brauer and Backholer 2009).

2.4. Approaches towards integrated production and transportation planning

The previous sections have shown that both, production scheduling as well as transportation planning, would benefit from a closer coordination. While this idea already has been addressed in a number of studies (Chen 2004), the focus has mainly been on models and problem formulations. A large number of problems include set-up-costs, which usually do not occur in automotive assemblies. Chen (2008) provides a review of „Integrated Production and Outbound Distribution Scheduling“ problems (IPODS) and analyses their complexity. Scholz-Reiter et al. (2008) further illustrate, how capacities, lot sizes and delivery dates can be integrated into production scheduling. Jin et al. (2007) present an integrated approach to reduce production and distribution costs (stock, transport). They simplify the problem by introducing a new type of sequencing rule, which results in savings of about 7,5% compared to the original solution. While these publications have provided valuable insights into models and algorithms, little research has been carried out on how to transfer the results into industrial praxis.

3. THE IMPACT OF DATA QUALITY ON INTEGRATED PLANNING

One major issue in transferring research results into the industrial praxis and in developing solutions that are relevant for practitioners is the handling of planning data. During integrated production scheduling and transportation planning, different organizational entities have to provide, exchange and retrieve planning data.

Categories	Dimensions
Intrinsic	Believability
	Accuracy
	Objectivity
	Reputation
Contextual	Value-added
	Relevancy
	Completeness
	Appropriate Amount of Data
Representational	Interpretability
	Ease of understanding
	Representational Consistency
	Concise Representation
Accessibility	Accessibility
	Access security

Table 1: Data quality dimensions

It is widely acknowledged, that the quality of decisions made depends heavily on the quality of the information available at hand to make those decisions. Data quality has been previously described as a multi-dimensional construct. Wang and Strong (1996) have identified 15 relevant dimensions in an empirical study and classified them into the groups intrinsic, contextual, representational and accessibility data quality (Table 1).

Raghunathan (1999) shows that in addition to data quality the decision maker, especially his understanding of the problem and the relationships between its variables is a second important aspect. Eventually, it is important that users (Bovee 2001):

- are able to get information (**accessibility**)
- are able to understand it (**interpretability**)
- find it applicable to their specific domain and purpose of interest (**relevance**) and
- believe it to be credible (**credibility**).

4. THE VIRTUAL SCHEDULING AND TRANSPORTATION MODEL (VSTM)

4.1. Concept and Application

Due to the described increasing number of involved organizational units in the process of production planning and order scheduling, the demand of an integrated information model for these processes and the transport planning is obvious. The VSTM concept does not aim at the replacement or complete substitution of the existing system infrastructure. It should be seen as a virtual model that can be linked to the existing system infrastructure by interfaces (see figure 2). Apart from the big advantage of one central point of access to a valid data base, the VSTM can be extended by further functions, which are necessary for innovative scheduling considering logistic requirements.

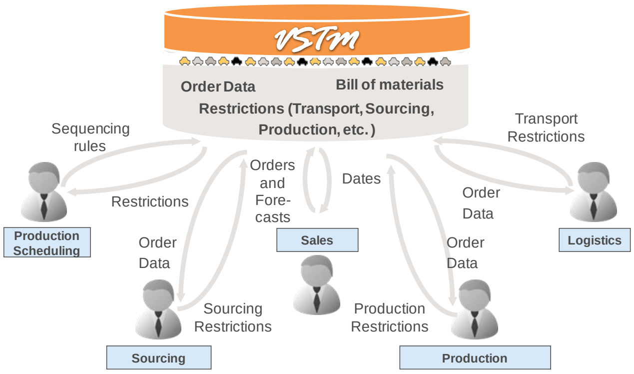

Figure 1: Concept of the Virtual Scheduling and Transportation Model

For gathering the information relevant for innovative scheduling with logistics constraints, interfaces to existing systems can be used. Additional data that are not available in today's processes emerge from new sub processes of individual organizational units during the scheduling. Fundamental information that must be provided by the VSTM is the description of the vehicles with their properties. This data basis covers the availability of individual products and properties in various markets. Moreover, it contains the bill of material and a list of properties that can be combined in a vehicle.

Based on the information provided about vehicles and properties and their availability in particular markets, sale forecasts can be made. These forecasts are the basis for the following production planning. An important aspect of the forecasting and planning process is to use all current information that is available in the network. Today, forecasting of volumes and property quantities is often carried out in different processes and by different organizational units. The initiative of the Californian government to advance small biodiesel vehicles is an example of available information that can be used for forecasting volumes and property quantities. It suggests an increase of volumes for small cars and also for the quantity of diesel engines.

Another opportunity is the generation of forecast orders. The forecast orders are derived from the forecast volumes and take property quantities into account. Additionally, the feasibility of property combinations has to be assured to generate valid and fully specified orders. In the VSTM concept, historical data are used to generate an automated forecast for properties, which are not forecast by the sales department. This procedure provides fully specified and valid forecast orders months before start of production. All further planning processes, such as the explosion of the bill of materials, benefit from this approach.

The use of forecast orders in production scheduling offers high information accuracy and allows the consideration logistic requirements. Within the VSTM the forecast as well as dealer or customer orders are booked against production and transportation capacities. Furthermore, a simulation mode for order booking is added to the VSTM. It enables the planner to asses the impact of a production plan and order sequence in advance.

The sequencing algorithm considers both, production and logistics restrictions and requirements (e.g. the fast formation of transportation lots in the distribution). It can be already applied to the forecast orders. Hence, excessive or inefficient capacity utilization of particular relations can be identified early, thus giving transportation managers more time to react.

Besides logistics capacities on different relations also production capacities are available in the VSTM. For the booking of production capacities it is necessary to describe the available maximum capacity as well as the current planned shift model. This includes information about shift duration and flexibility as well as the factory calendar. The booking functionality of the VSTM ensures that the maximum production capacities are not exceeded. However, in the course of a planning update the shift model is also considered flexible and can be adapted to the planned production volume.

After entering the first demand forecast, the forecast orders are continuously replaced by actual customer or dealer orders. Hereby, updates of the data base can take place at regular intervals or event-driven throughout the program planning and sequencing process. The objective in developing an adequate optimization algorithm for the order sequencing is to ensure a high stability of the original order sequence throughout the whole planning horizon.

In sum, the concept of the VSTM itself does not impose any restrictions on the workflow of production planning, order sequencing and transport planning. Therefore, it is applicable to various companies.

4.2. Impact on data quality

The concept of the VSTM provides access to required information for all relevant planning domains and serves as a common information basis. It has been designed to improve data quality and provide an interface for integrated production scheduling and transportation planning. The **accessibility** of information is increased by the VSTM concept. The VSTM provides a central virtual information model. Using interfaces, latest planning data will be transferred to the VSTM immediately. Each organizational unit and planning domain can then access the same data directly. Another benefit is, that the processes of production and transportation planning do not have to be synchronizes. Each entity can access and amend data according to its schedule. The **interpretability** is also enhanced because all planning data regarding the production program are derived from fully specified and valid forecast orders. This reduces inconsistencies and misunderstandings. Even though the VSTM provides a holistic data basis, the **relevance** of the data provided for a single organizational entity is high. By using customised interfaces and queries for different planning domains and organizational units, the available data can be focussed on the relevant data for a concrete planning process. An information overflow is avoided. The **credibility** of the planning data is maximised by the use of fully specified and valid orders. The shift to an order based planning increases the validity of all planning data as no inconsistence can occur. All entities work with the same data set and are informed immediately if changes occur or forecast volumes are reduced.

5. TWO LEVERAGES FOR INTEGRATED PLANNING

5.1. Adjustment of logistics to changing production programs

With the help of the VSTM current data can be accessed by logistics planners at any given time. This sections describes, how transportation planning can be coordinated with production planning by using the VSTM as an interface.

The order data retrieved from the VSTM are used to update the database for transportation planning. Hereby only relevant data at a suitable level of detail are processed. The estimated demand for production is then directly mapped on the current network. This innovative procedure yields transparency about the status quo of the transport network. Where are the major material flows? Will there be significant changes? Do the capacities suffice? These questions can be answered by automated analyses that depict the flows and capacities hence providing insights about current opportunities for transport consolidation, and possible cost-cutting measures. All possible measures can be compared and evaluated using state-of-the-art optimisation algorithms. They are then coordinated with logistics service providers, suppliers, and other parties involved. The benefit of continuously checking and adjusting the transportation network to production volumes is depicted in Figure 2. While in the left picture overcapacities and extra transports cause elevated transport costs, the right picture shows a coordinated scenario.

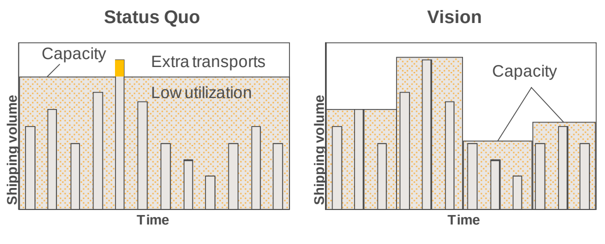

Figure 2: Adjustment of capacities to production volume improves utilization

The time needed ahead of transport execution for changing the transportation concept depends on the logistics flexibility of the firm and its service providers. The higher the logistics flexibility, the later the last dead line for changes in the transportation concept.

Figure 3: Logistics parameters in production scheduling

Measures that have been evaluated, coordinated, and approved are then implemented. This, of course, can result in different requirements for production scheduling (Figure 3). The information in the VSTM is updated to ensure that future production plans can incorporate the new requirements.

5.2. Adjustment of production sequences to logistics

The adjustment of production sequences to logistics requirements is designed as a two-staged process. The first step is the adjustment to requirements from distribution logistics. Feasible transports are determined before the order booking. Orders will then be booked on discrete transports. Several rules for the order allocation are imaginable. In a first application inside a case study, the main rule was to maximise the utilisation of train transports. Backward scheduling from the desired arrival at the dealer site is used to determine the latest possible production end that will ensure the on time distribution of the product. In case of a scheduled transport e. g. by train, all products that are booked on this train will have the same timestamp for the latest feasible production end. Orders for the same relation and transport are bundled. The bundled orders shall be produced immediately before the scheduled transport to avoid unnecessary stock keeping and capital costs during the build-up of a transport.

The second stage is the application of sequencing rules for building the production sequence to avoid capacity overload at single working stations and to ensure a smooth utilisation of capacities. The consideration of logistic requirements derived from the inbound logistics can also be realised by such sequencing rules.

The final production plan is built by applying optimisation algorithms on the available order pool. As it is not possible to respect every single sequencing rule at any time, the violation of sequencing rules has to be associated with penalties. Different penalties can reflect the relevance of a certain sequencing rule.

6. PROTOTYPAL IMPLEMENTATION AND NEED FOR FUTURE RESEARCH

The feasibility of the VSTM and the integrated production scheduling and transportation concept will be demonstrated by a prototype. Therefore the two standard software tools 4flow vista of the 4flow AG and OTD-NET of the Fraunhofer IML will be used together and equipped with additional features.

4flow vista is a widely applied integrated standard software for supply chain design. It automates and accelerates often-repeated and time-consuming activities of designing and planning logistics structures and processes. In the field of strategic transport planning the software helps to improve the transparency of the transportation network in order to identify and eliminate inefficiencies. Moreover it is possible to plan or re-schedule transports and thus create efficient and flexible transportation structures. In order to provide support for integrated production scheduling and transportation planning 4flow vista will be extended with further features for intermodal transportation planning. Moreover innovative methods for quickly adjusting transportation networks to changing production volumes will be added.

OTD-NET is a tool for event discrete simulation of value-added networks and order execution processes (Wagenitz 2007). The design of deployed models can vary in the level of detail depending on the aims of a study (Motta et al. 2008). OTD-NET will be used to demonstrate the functionalities of the VSTM. The required forecast orders will be generated by the simulation tool. Algorithms for order booking on transports and sequence optimization will be implemented. Overall, the simulation based approach allows determining the influences of logistic orientated production scheduling on the entire network.

Further steps in this research will include the specification and implementation of the prototypes and their application in case studies. The description of work-flows and planning hierarchies is another important aspect. Last but not least a road map for the adaption of these results into industrial praxis will be developed.

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