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Abstract
The production sequence of European car manufacturers at present is built based on constraints of the production factors in production like material, equipment or workforce. Through the integration of logistics constraints in the outbound supply chain, transportation processes in terms of CO₂ emissions and transportation costs can be improved. In a research project, the integrated planning of production sequence and logistics transports for vehicle manufacturers was tested for feasibility. The project results show that the introduction of logistics constraints in production scheduling is possible and that logistics savings can be significant.

Keywords
Transportation, Outbound Logistics, Automotive, Production Scheduling

1 INTRODUCTION
Production scheduling in the Automotive Industry for sequenced assembly lines is the matching of the required capacities out of the production program with the existing fundamental factors of production. Workforce, equipment and material are the three basic planning sectors (see Figure 1). They can be defined as planning constraints in production scheduling determining the output of the production system. Current planning algorithms try to create a valid production sequence under consideration of all given production constraints.

Such restrictions narrow the solution space by prohibiting certain events or sequences of events. By introducing additional logistics-oriented constraints to production scheduling, an optimization of transport parameter like costs or CO₂ emissions can be achieved [2].

The project InterTrans, supported by the German Ministry of Economics and Technology, the Austrian Research Promotion Agency (FFG) and the European research initiative EUREKA, had the aim to research the possibilities in the European Automotive Industry to increase capacity utilization of transport means, to reduce kilometres travelled to supply Automotive production with parts (inbound transportation), to deliver finished cars to the customer (outbound transportation) and to determine the possibility to shift transports from truck to more eco-friendly transportation modes like ship or railway.

2 PRODUCTION CONSTRAINTS FOR SEQUENCED ASSEMBLY LINES
The Automotive Industry produces according to the principle of a high-variant line production [3]. The production sequence on the assembly line is a result of a constraint planning. There are two types of constraints: Inherent constraints which are balancing equations or conditions and are valid for the complete production system and second task related constraints which represent technological, organizational and economic characteristics of the production system [4]. Task related planning constraints are relevant for the planning of the production sequence on assembly lines. Hence the originators of planning constraints are generally classified within five groups: Equipment, Workforce, Material, Product and Market. These five groups build the branches of the Ishikawa-diagram in Figure 2. [5]

The upper three branches represent the fundamental factors that describe the production system. They are essential to achieve the required output:
- Equipment
- Workforce
- Material
The output of the production system is characterized by the branch \textit{Product}. It defines which brands, models and types are available for the customer and how those products can be configured. The last branch of the diagram – the \textit{Market} branch – represents all customers and their requirements as well as the outbound logistics which became more important as minimization of transport is in focus [6]. All described constraints can be defined as absolute or relative constraints [4]:

- **Absolute constraints** are quantity or time constraints. A quantity constraint has a variable quantity and fixed time period (e.g.: the weekly capacity is 1200 parts.). On the other hand time constraints have fixed quantities and a variable time period (e.g.: a product carrier has a capacity of ten components and it is just shipped when the carrier is full).

- **A relative constraint** is always characterized by a combination of at least two events. Such constraints are for example sequence or distance constraints. A sequence constraint for example prohibits that a white car body is followed by a black body in the paint shop. The distance constraint can define that there are three cycles required until the same option is allowed to be assembled again.

Relative constraints are mainly relevant in the short-term planning process (sequencing). In long- and mid-term planning the relative constraints have to be translated to quantity or time constraints. For example the distance constraint that there are three cycles required until the same option is allowed to be assembled again has to be transferred into a quantity maximum of a third of the daily maximum in long- and mid-term planning as there is no information on the exact sequence available yet.

When the limit of a constraint is flexible and can be exceeded for example under acceptance of higher costs they are called soft constraints. Other restrictions that are often caused by technological limitations cannot be exceeded and must be seen as hard constraints - they cannot be violated. An example of a soft restriction is a weekly delivery lot size of a supplier that can be exceeded under special conditions.

### 3 TRANSPORT PLANNING IN THE AUTOMOTIVE INDUSTRY

The task of the transport planning can be divided into the design of the network and the planning and control of the executed transport processes. The task can be segmented into: [7]

- **Design of transport network** (long-term)
- **Planning of transport routes and means of transports** (mid-term)
- **Planning of vehicle usages** (mid and short-term)

The design and the long-term planning define sources, nodes and drains of the automotive supply chain (suppliers, cross docks, component factories, automotive plants, transhipment points, dealers etc.) and the transportation network of roads, rails and waterways. These networks are used to forward freight between origins and destinations of the production network. Shipments may be transhipped from rail, road and water to the same or another transport mode using adequate facilities. [8]

The short term transport planning takes the result of the production scheduling and assigns the derived demand to the available transport capacities. This transport planning process is highly reactive and leads to inefficiencies like higher logistics costs or unnecessary CO$_2$ emissions. [9]
4 LOGISTICS RESTRICTIONS TO IMPROVE EFFICIENCY IN TRANSPORT LOGISTICS

In order to improve this transport planning process, it is necessary to define strategies for a higher efficiency of transport logistics.

One can distinguish between ecological and economic efficiency. Efficiency describes the extent to which effort is used for the intended task or purpose – economically in terms of total costs and ecologically in terms of external effects caused by the transport (ex. CO₂ emissions, pollution, noise). The aim to increase efficiency can be reached by:

- Shift of carrier or transportation means (more ecological or more economical)
- Traffic reduction or avoidance
- Optimization of capacity utilization of the carrier

Ecological and economical aims can be conflicting (shift of carrier may be ecologically good but economically bad) or common (an increase in capacity utilization and traffic reduction or avoidance is ecologically and economically favorable; total costs and unwanted external effects are reduced).

In order to reach the goals to increase efficiency, several measures in production sequencing can be taken to positively influence these three aims.

4.1 Shift of carrier or transportation means

From an ecological point of view, rail or ship transports can be generally considered as more efficient than truck transports. The characteristic trait of these two transport modes is their higher capacity. For example the capacity in outbound logistics of a train is approximately 200 cars whereas a truck capacity is 8 cars. To support the shift of carrier to rail or water, a planning strategy to bundle the car production from or for a specific destination according to their time schedule would be favorable.

4.2 Traffic reduction or avoidance

The bundling of cars for the same outbound destination is also an appropriate strategy for the traffic reduction or avoidance. Bundling means to concentrate the demand of cars of specific markets into a shorter time span. By bundling cars, which are supplied over the same transport relation, high transport utilization can be achieved. A traffic reduction can also be realized by a consolidated transport instead of direct deliveries.

4.3 Optimization of capacity utilization of the carrier

The principle of bundling under consideration of the carrier capacity can optimize the capacity utilization and as a result it can reduce or avoid traffic. This should be combined with the smoothing of demand over several planning periods in order to optimize the capacity utilization and the planning process. A weekly train to supply the demand of a specific market for example can only be considered as ecologically efficient if the fluctuation of capacity demand does not frequently exceed the maximum capacity. The resulting disturbances and the need of additional transportation of the overrun may reduce or negate the benefits.

Smoothing means realizing a steady demand of parts. The resulting constant stock movement and flow of cars provide a basis for a steady transport schedule [11].

4.4 Summary logistics restrictions

To summarize, the following planning restrictions in the production scheduling would provide ecological and economic efficiency in transportation: [12]

- Capacity oriented bundling of cars for destinations or markets (cars for a specific region with the same ship carrier can be bundled)
- Smoothing over several periods
- Timing according to a schedule (timetable)

Occurring conflicts in ecological or economical aims in the case of a shift of carrier or transportation means must be solved by a prioritization decision.

5 PROJECT PROCEEDING

Sequencing in the Automotive Industry is the planning process where assembly orders for a specific time period (e.g. a day or shift) are brought to an optimal sequence assuring a consideration of different lead times of orders as a result of different variants. The assembly order should not break any restrictions and should maximize the capacity utilization of every station. Exact optimization approaches are not applicable in practice due to long calculation times. Therefore several heuristics are used to find a practicable assembly sequence (see [13], [14], [15], [16]).

Most of the Western European car manufacturers use the car sequencing algorithm (car sequencing problem, CSP). CSP does not work with detailed car configuration information, but ban overloads of partial sequences with so-called “Ho:No-rules”. These rules determine that among “N” consecutive sequence positions at most “H” occurrences of a certain option “o” are allowed. A sequence which does not violate this rule also ensures the avoidance of a work overload at the several work stations. One example for a rule of Ho:No of 1:3 for the option sunroof says that from three sequenced orders only one order can contain a sunroof.

After the appliance of the algorithm on the entirety of the orders, from No sequenced variants, the maximum amount of Ho options can be included to assure no overloads.

One aim of the project InterTrans was to prove that it is possible to integrate logistics restrictions in the sequencing algorithm in addition to existing
production oriented restrictions in order to improve the usage of transport means (short term). Current sequencing algorithms in the Automotive Industry are not considering logistics restrictions at all. Therefore logistics restrictions for the production sequencing process had to be formulated and tested, if still a valid production sequence can be generated after the introduction.

To optimize transports, a temporary adjustment of demand (bundling, smoothing) is necessary. In the distribution logistics the time of departure of the transport means is an important parameter to optimize. Introducing a latest completion time for orders, the optimization criteria: a) “minimize the amount of takts between completion time and latest completion time” and b) “minimize the amount of orders with a completion time after the latest completion time” leads to a bulking of orders around the latest completion time. This can be considered as favorable for rail or ship transports and therefore for more ecological transportation. For smoothing, the planned production quantities for specific markets or outbound destinations over a certain time period must be constant.

To validate the effectiveness of the new smoothing and bundling rules in production scheduling for outbound logistics, the distribution network of a German automotive plant was modelled and examined and tested under realistic conditions with historic demand data sets.

One of the most important logistics restrictions is the storing capacity of finished cars in the production plant. To avoid an excess of the capacity limit, the load building time for block trains was restricted to 2.5 days.

Figure 3 shows that transport quantities per outbound destination per day have a considerable fluctuation range.

![Figure 3 - Production factors [12].](image)

Figure 4 shows the transport concept before introducing the logistics restrictions to the production scheduling. It is dominated by a high truck usage and only one bulk train to supply the 27 destinations. Through the consolidation of quantities for destinations 1 and 2, as well as destination 3, 4 and 5 a shift to bulk train transport for the main leg could have been established. Figure 5 shows the outbound transport concept per transport relation after applying the logistics restrictions of the InterTrans project. A significant portion of the transport volume could have been shifted to bulk train transport which is economically and ecologically favourable.

![Figure 4 - Current outbound transport concept per transport relation [12].](image)
6 PROJECT RESULTS

In order to include these logistics requirements in production planning, integrated information from production and logistics is necessary. New processes for a dynamic transport planning and a logistics-integrated sequencing were developed and combined into an overall planning process. A software tool to dynamically plan the transportation was realized as a prototype (see Figure 7).

The dynamic planning of transportation processes and capacities leads to an increase in efficiency and flexibility also in mid-term transportation planning aspects. For example, by opening up the possibility to dynamically assign a transport means with appropriate shipping volume or to switch the transportation concept from a direct transport if the shipping volume decreases to a milk-run concept, significant savings can be achieved.

6.1 Impact on Outbound Logistics

In distribution logistics, finished cars are assigned directly to the transport device. The integrated planning of the sequence and the transport has the following overall aims (see Figure 6):

- Maximization of capacity utilization
- Preference for Transports with better ecological efficiency
- Minimization of stocks (to avoid additional handling after the end of the production process)
- Keeping the deadline of the customer order
In case studies a double-digit percentage rate for the reallocation of truck transports towards train transports outbound has been proven. Also the stock level of finished vehicles before distribution was reduced by over 20%.

7 CONCLUSIONS
The project InterTrans proved that the introduction of logistics-oriented planning restrictions in the production planning and scheduling process has a very positive impact on the efficiency of the transportation logistics. The integrated planning of logistics and production in the Automotive Industry is not only feasible in practice, but showed significant improvements in the logistics efficiency without affecting the production adversely. The dynamic transportation planning, the logistics-oriented planning constraints and the holistic planning process developed in InterTrans lead to a couple of improvements compared to the current situation in the Automotive Industry. Improvements include:

- Utilization of dynamic bundling capabilities (reduction of transport)
- Improved capacity utilization of the transport carriers (up to 9%)
- Reallocation of cars towards ecological transportation means (reduction of truck kilometers up to 48%)
- Reduced distribution times
- Reduced of CO\textsubscript{2}-emissions
- Reduced stock level of finished vehicles before distribution (up to 23%) and less handling costs
- Improved communication between all partners in the Automotive supply chain
- Improved planning quality and reliability

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9 REFERENCES
10 BIOGRAPHY

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