A FRAMEWORK FOR THE INFORMATIONAL INTEGRATION OF PRODUCTION AND TRANSPORT SYSTEMS

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ABSTRACT

In present manufacturing and transportation systems information concerning current capabilities and employment level are not appropriately utilised to determine most effective plans. Therefore, cost and lead-time savings obtained with new manufacturing strategies might be impaired due to an unbalanced and unstable integration of production and logistics. This paper proposes a framework for investigating interfaces between production and transport systems along global supply chains. Since supply chains comprise legally independent partners, the framework does not only aim to pave the way towards an integrated production and transportation scheduling for an OEM but rather for a whole supply chain. For achieving this aim scheduling entities are introduced at the operational level and a mathematical program of the integrated production and transportation scheduling problem for one entity is formulated and tested. Obtained results and the limited size of computationally manageable scenarios are both motivation and starting point for the development of forthcoming heuristics.

RESUMO

Informações quanto a capacidade e o nível de utilização atual dos sistemas de manufatura e transporte não são apropriadamente utilisadas para aprimorar o planejamento de produção e logístico. Dessa forma, ganhos de custos e tempo de execução obtidos com novas estratégias de manufatura podem ser prejudicados por conta da integração desbalanceada e instável dos sistemas produtivos e logísticos. Este artigo propõe uma estrutura para a investigação das interfaces entre tais sistemas ao longo de cadeias globais de abastecimento. A referida estrutura objetiva pavimentar o caminho em direção a um *scheduling* integrado para toda a cadeia de abastecimento. Para tanto, entidades de *scheduling* são posicionadas no nível operacional e uma formulação matemática do *scheduling* integrado de produção e transporte em cadeias de abastecimento é apresentada e testada. Os resultados obtidos, bem como o limitado tamanho dos cenários computacionalmente gerenciáveis constituem motivação e ponto de partida para o desenvolvimento de novas heurísticas.

1. INTRODUCTION

For benefiting from country-specific advantages, contemporaneous supply chains often embrace distributed manufacturing systems. In addition to this, several companies have concentrated on core competences and outsourced logistic processes to service providers. Both developments contributed to increasing structural complexity and dynamics within supply chains. Effective connections among partners should be fostered in order to materialise supply chain competitiveness (Christopher, 1992). Strategic, tactic and operational interfaces between manufacturing and logistic systems must be designed and implemented taking this competitiveness view into account.

Technological tools that make information exchange possible have improved supply chain efficiency. Yet, the evolution in this field is still impaired due to some conceptual deficits, mainly in regard to the integration of transport information into production planning and control systems. Thereby a large potential for further improvements in the competitiveness of supply chains exists. To illustrate existing integration deficits it is possible to spot that in current production planning and control as well as advanced planning systems (APS's), information regarding transport capabilities and its level of employment is not being appropriately employed to determine the most effective production schedule. Furthermore, in supply chains advanced planners from different stakeholders synchronise production planning by considering mean values of transport lead-time.

This research focuses on the informational interface between production and transport systems along supply chains. More specifically, it deals with the integration of transport information into production planning and control systems. A framework for investigating strategic, tactic and operational interfaces between manufacturing and logistic systems along supply chains is proposed. This framework will pave the way toward modelling and analysing informational integration concepts and methods. On the long-term, a heuristic for the integrated scheduling of production and transportation processes will be pursued as well. In the present paper, a mathematical program of the integrated production and transportation scheduling problem on the operational level is developed and tested. Production scheduling is adapted to a flow-shop with several production levels that contain multiple machines. An open vehicle routing formulation is employed for the transport scheduling. Obtained results and the limited size of computationally manageable scenarios are both the motivation and starting point for the development of a forthcoming heuristic.

2. INTEGRATION OF PRODUCTION AND TRANSPORT SYSTEMS

In order to enhance decision making in a dynamic and competitive environment, resources and their employment have to be better considered in production planning and control systems as well as logistic systems. Production and transport scheduling will be introduced as potential sources of insight and knowledge for the forthcoming development of an investigative framework.

Planning and control systems underpin manufacturing performance and have been broadly adopted. The underlying architecture of modern advanced planning systems (APS) can be illustrated by the Supply Chain Planning Matrix (Rohde *et al.*, 2000). The matrix comprises modules for the planning tasks that can be characterised by time horizon (strategic, tactical, operational) and involved business functions (procurement, production, distribution and demand forecasting). Usually the planning tasks on the strategic (strategic network planning) and tactical level (master planning) are carried out by a central planning entity in order to align all future activities of all locations.

Due to the large amount of data that needs to be considered and the number of decisions, the operational planning is carried out in a decentralised manner at each location and for each business function. Thus material requirements planning, production planning and scheduling as well as distribution and transportation planning are carried out independently in a sequential way (Fleischmann *et al.*, 2004). These individual planning tasks are performed by model-based decision systems that often include the utilisation of mathematical models or heuristics for determining optimal solutions. So far, these models do not take dynamic environments or stochastic events appropriately into account. First approaches for overcoming this shortage have been presented (Scholl, 2001; Kuhn e Gebhard, 2008). The dynamical integration of production and transportation scheduling at the operational level holds a great potential for strengthening supply chain's competitiveness. Furthermore, significant improvements can be achieved by an integrated scheduling compared to a sequential scheduling approach (Chen e Vairaktarrakis, 2005).

The integrated production and transportation scheduling problem (PTSP) with capacity constraints is well known in the literature. An optimal solution for the PTSP requires solving the production scheduling and transportation routing simultaneous. The nature of these problems leads to a mathematical program, which is NP-hard in the strong sense. Therefore even for small scenarios an excessive computational power is needed. Thus the challenge is to set up heuristics that can timely lead to near optimal solutions/schedules. Furthermore, the classic PTSP focuses on constraints connected rather on the production capacities than on the transportation times and costs (Hochbaum e Hong, 1996; Tuy *et al.*, 1996; Sarmiento e Nagi, 1999). These approaches often assume the transportation to be instantaneous and do not address the routing of the transportation vehicles.

Several concepts for the integration of production and transportation have been developed in the recent years (Sarmiento e Nagi, 1999; Thomas e Griffin, 1996; Fumero e Vercellis, 1999). But most of these concepts focus on the strategic or tactical planning and scheduling (Chen, 2004). Research dealing with detailed schedules for the transportation can be classified according to the objectives of the applied mathematical programs and heuristics. One group only considers the lead time for orders' production and transportation (Potts, 1980; Woeginger, 1994; Lee e Chen, 2001; Hall *et al.*, 2001; Geismar *et al.*, 2008).The other group takes associated costs and lead times into account (Chen, 1996; Cheng *et al.*, 1996; Wang e Cheng, 2000; Hall e Potts, 2003; De Matta e Miller, 2004; Chen e Vairaktarrakis, 2005; Pundoor e Chen, 2005; Chen e Pundoor, 2006; Stecke e Zhao, 2007). Although the determination of detailed schedules for the production and transportation is already a good achievement, the transportation system also comprises the routing of transportation vehicles, which should be based on the current capabilities of transportation system. This challenge has only been addressed by a few authors (Li *et al.*, 2005; Geismar et al., 2008).

Aforementioned research is dedicated to the application in special settings and, therefore has limited capabilities. To sum up, existing approaches are not applicable for a generic supply chain structure; do not consider stochastic events or rolling planning horizons; and do not analyse routing decisions.

3. INVESTIGATIVE FRAMEWORK

The investigative framework will pave the way for the development of a heuristic scheduling scheme that is applicable for a supply chain comprising several production facilities in a row; can be run in a successive way; considers the schedule from the previous iteration; takes the current production and transport capabilities into account and enables the entities to shift delivery dates. The aim of the heuristic is to meet a certain service level in regard to the delivery of the orders in time and to minimise the costs for production and transport.

Even though centrally planned and controlled supply chains could lead to global performance optimisation, centralised solutions are not practically applicable due to overwhelming eyesight and communication requirements. The design of advanced planning systems takes this into account and separates the performed tasks according to their time horizon and execution level into strategic, tactical and operational (Rohde et al., 2000). In regard to production and transportation scheduling, most literature deals with integrated concepts from a strategic and tactical viewpoint (Potts, 1980). On the operational level, production and transportation scheduling are carried out through a decentralised and sequential way due to their complexity and current lack of appropriate heuristics for an integrated scheduling. The performance of a supply chain could be significantly improved – in terms of both service level and costs – by applying an integrated instead of sequential scheduling approach on the operational level (Chen e Vairaktarrakis, 2005).

Current approaches focus on the integration of production scheduling of an OEM and the distribution of orders to the customers. These schemes have to be extended to be suitably applied for a whole supply chain. Therefore, we propose the introduction of scheduling *entities* along the supply chain that could carry out the integrated scheduling for one production facility and associated transportation to the next production facility. The tactical level aligns these entities by specifying order delivery dates to the subsequent entities. In order to enable the entities to resolve orders' poor schedules / specifications that cannot match their delivery date, the entities need to have the flexibility for shifting delivers date according to certain mechanisms. Consequentially each entity has not only to set up a production and transportation schedule that is suitable for its own specifications of delivery dates but also for the specifications of directly connected entities.

So far no proposed scheduling scheme in the literature takes the rolling planning horizon of the performed operations into account. However a scheduling scheme at the operational level needs to be run in successive way. Indeed, each iteration has to consider the existing schedule from the previous iteration as well as new orders. In the intervening time between these iterations, capabilities and employment level of involved production and transportation system may change due to either planned or stochastic events. Also these dynamic effects will be properly taken into account in the forthcoming integrated scheduling heuristics. The following Figure 1 sketches the concept and characteristics of the proposed heuristic for the integrated production and transportation scheduling.

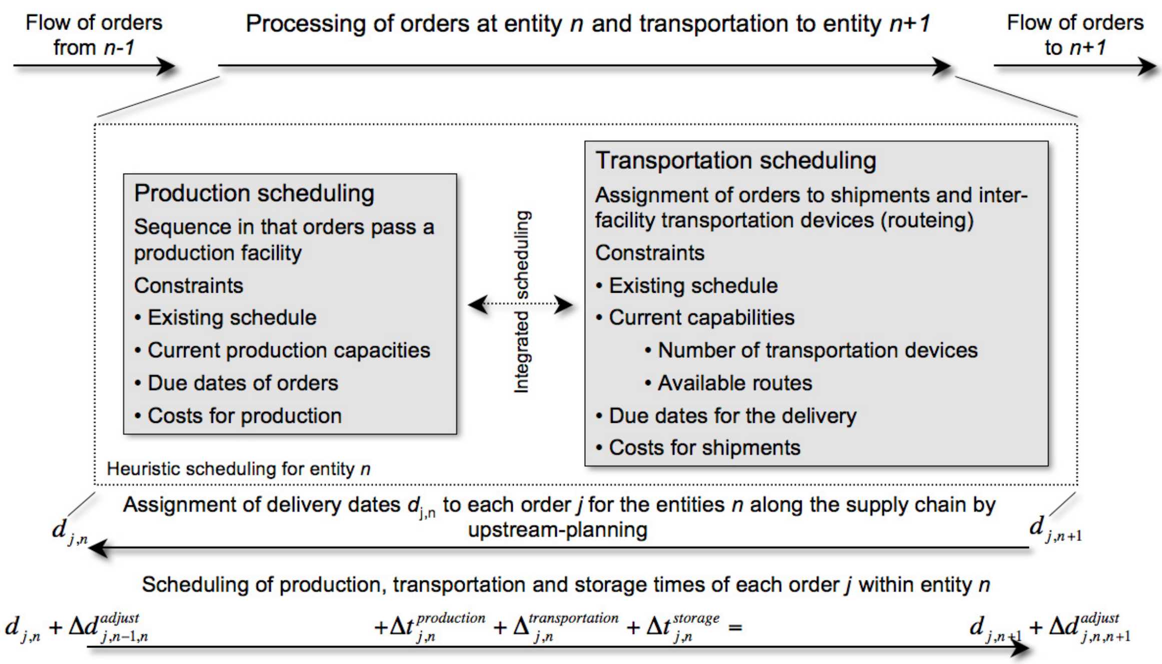

Figure 1: Proposed heuristic for the integrated scheduling

The scheduling of the orders is based on the order delivery dates $d_{j,n}$, which are provided by upstream planning. The aim of the heuristic is to meet a certain service level in regard to the delivery of the orders in time and to minimise the costs for production and transportation. Therefore a schedule for all orders is set up and the dates for production, transportation and if necessary for storage are specified. This schedule is subject to the constraints given by the existing schedule, current capabilities of the production and transportation system, delivery dates of the orders and associated costs. Capabilities might change between two consecutive iterations of the scheduling either due to planned events like maintenance of a machine or a transportation device and as well as stochastic events like the breakdown of a machine or the flooding of a road. Such operational events or poor specifications from the tactical level illustrate the need for a mechanism to adjust the order delivery date between the entities along the supply chain. Thus it shall be possible to shift the $d_{j,n}$ by $\Delta d_{j,n,n+1}^{adjust}$.

Finally, the proposed heuristic will be implemented in order to enhance the knowledge about the involved tradeoffs and characteristics of an integrated production and transportation scheduling, which considers the capabilities and employment level of involved manufacturing and logistic systems.

3.1. Adaptation of the production and transportation scheduling problem

The first steps of the investigative framework will be carried out in a scenario where a single company owns all production facilities and transportation devices. Hence, the scenario can be regarded as a special situation for the scheduling problem since inter-organisational barriers for the collaboration among agents along the supply chain do not exist.

The work is initiated with the setup of a mathematical program, which represents a formulation of the integrated production and transportation scheduling problem for one entity. The capabilities of the production scheduling and routing problem are expressed by the constraints of the program. The objective function will balance the desired service level and the associated costs for production and transportation. Due to the rolling planning horizon the program needs to be run in a successive way by taking the schedule from the previous run, new orders as well as current capabilities and employment level of involved production and transportation systems into account.

Since the underlying mathematical program for one planning entity is NP-hard in the strong sense, a small test scenario of a supply chain is set up. Within the framework this test case will be used on the one hand to develop the scheduling scheme and on the other hand as a benchmark for a forthcoming heuristic.

3.2. Proposed formulation of the PTSP

Section 3.2 introduces a mathematical formulation of the PTSP for a given entity within the supply chain. Therefore, the characteristics described in section 3 will be considered.

Nomenclature

Sets

I	Nodes of the transportation network
I^D	Production facility of the transportation network $\left(I^D \subseteq I\right)$, here only one depot exists
I^{SF}	Subsequent production facilities within the considered transportation network $\left(I^{SF} \subseteq I\right)$, here only one subsequent production facility exists
I_i^s	Locations that are directly connected to location i; with $\left(I_i^s \subseteq I\right)$

J Orders from subsequent facility i
T Order types
$T^{j}_{j,t}$ Assignment of orders j and order types t; only one order type per order
N Production levels of the production facility
M Machines
M^{e}_{n} Available machines at production level n; with $\left(M^{e}_{n} \subseteq M\right)$
V Tours for the delivery of orders to successive facility
$L^{tour}_{j,v}$ Pre-given assignment of orders j to tours v; only for first tour
$L^{seq}_{j,j'}$ Pre-given sequence of order j and j'; only for first orders

Parameters

c^{d} Costs for a delayed delivery of order j
c^{dv} Costs per time unit for a tour v
c^{fv} Fixed costs for conducting a tour v
c^{h} Storage costs of an order at the depot
$c^{p}_{j,t,n,m}$ Processing costs of order j at level n on machine m
$d_{i,i'}$ Travel time between node i and node i'
M BigM; large scalar
$pt_{j,t,n,m}$ Processing time of order j at level n on machine m
r_{j} Required transportation capacity by order j
$\bar{r}_{v}$ Maximum transportation capacity of tour v
$t^{a}_{j,n}$ Supply date of order j by the tour from the preceding production facility
t^{av}_{v} Earliest date of departure of tour v from the production facility
$t^{dd}_{j,i}$ Desired delivery date of order j at the subsequent facility i

Positive Variables

$T^{c}_{j,n}$ Completion time of order j at machine m at production level n
T^{d}_{j} Delivery delay of order j to the subsequent production facility
T^{h}_{j} Storage time of j between the supply date and the start of production at production level n
$T^{hp}_{j,n,n'}$ Storage time of j between consecutive production levels n and n'
T^{hv}_{j} Storage time of j between the last production level and the start of the assigned tour
T^{s}_{v} Start time of tour v from the production facility
$T^{a}_{v,i}$ Arrival time of tour v at location i
T^{dv}_{v} Duration of tour v

Binary variables

$X_{j,n,m}$ Binary variable denoting that order j is processed at machine m at level n
$Y_{j,j',n}$ Binary variable denoting that order j is processed before order j' at level n
$Z_{v,i,i'}$ Binary variable denoting that node i' is visited after node i by tour v

$A_{j,v}$ Binary variable denoting that order j is assigned to tour v

O_v Binary variable denoting that tour v is conducted.

3.3. Model assumptions

The mathematical program combines the production scheduling of one production facility and the vehicle routing for orders that have to be delivered to the subsequent production facility. As soon as a tour from a preceding production facility arrives at the considered production facility the processing of the associated orders can start. In order to schedule the production of these orders the mathematical program takes the desired delivery date at the subsequent production facility, capabilities of the manufacturing and transportation systems as well as the results of the previous schedule into account.

The applied production scheduling is based on a flow-shop with several production levels that contain multiple machines. Hence, orders (jobs) are processed at several consecutive production levels before the production is finished. Each production level can consist of several machines, which are characterised by different properties. In this case each machine features an order-type specific processing time and processing cost. All orders have to be processed at one machine at each production level. The orders can be stored before the start of production at the first production level, between production levels and before the assigned tour to the subsequent production facility departs. The storage of orders causes as well additional costs. In order to take the previous schedule into account the sequence of a set of orders at the first production level is considered as fixed. These orders have to be produced first.

An adapted open vehicle routing formulation is employed for the transport scheduling of orders to the subsequent production facility. The transportation of orders is conducted by assigned tours. Each tour starts at the considered production facility and ends at the designated subsequent production facility. A new tour becomes available as soon as a tour from a preceding production facility arrives. Within a certain tour each location of the transportation network can be visited only once. However, a location can be visited by several tours, in order to satisfy the demand of the subsequent production facility. A partial delivery of an order is not allowed. Each tour has a given transportation capacity, which cannot be exceeded by the assigned orders. In the case that at least one order is assigned to a tour, fixed and variable costs occur. The variable costs depend on the duration of the tour. However, only a minimal transportation time between two consecutive locations of a tour is enforced. By extending this time, orders can by stocked during their transportation. The actual delivery date of an order should be in line with the desired delivery date. In order to keep the model feasible an order can be delivered late but not early to the subsequent production facility. Costs for a late delivery reflect additional costs for manufacturing at the subsequent production facility. The results of a previous schedule are taken into account by a pre-given assignment of a limited number of orders and tours.

3.4. Mathematical model

The production of an order is assigned to one machine at each production level.

$$\sum_{m \in M_n^e} X_{j,n,m} = 1 \qquad (j \in J; n \in N) \tag{1}$$

The completion time of an order at a given production level is greater than the sum of the completion time at the previous production level and the required processing time of the assigned machine.

$$T^c_{j,n-1} + t^a_{j,n} + \sum_{m \in M^e_n} pt_{j,t,n,m} X_{j,n,m} \le T^c_{j,n} \quad \left(j \in J; t \in T : j,t \in T^j_{j,t}; n \in N\right) \tag{2}$$

Equations 3 to 5 schedule the processing of orders. Equation 3 ensures that the pre-given sequence of orders from a previous planning is enforced. Furthermore equation 4 and 5 ensure that at each point in time only one order is processed at a certain machine. Note that for one production level the sequence of all orders is the same at all available machines.

$$Y_{j,j',n} = 1 \quad \left(j, j' \in J : j, j' \in L^{seq}_{j,j'}; n \in N : n = 1\right) \tag{3}$$

$$Y_{j,j',n} + Y_{j',j,n} = 1 \quad \left(j, j' \in J : j < j'; n \in N\right) \tag{4}$$

$$\begin{aligned} T^c_{j,n} + pt_{j',t,n,m} \quad \le \quad & T^c_{j',n} \\ & + M(2 - X_{j,n,m} - X_{j',n,m}) \\ & + M\left(1 - Y_{j,j',n}\right) \end{aligned}$$

$$\left(j, j' \in J : j \ne j'; t \in T : j,t \in T^j_{j,t}; n \in N; m \in M^e_n\right) \tag{5}$$

Orders can be stored before and between the production levels. The storage times are obtained by equations 6 and 7.

$$T^h_j \ge T^c_{j,n} - \sum_{m \in M^e_n} pt_{j,t,n,m} X_{j,n,m} - t^a_{j,n} \quad \left(j \in J; t \in T : j,t \in T^j_{j,t}; n = 1\right) \tag{6}$$

$$T^{hp}_{j,n-1,n} \ge T^c_{j,n} - T^c_{j,n-1} - \sum_{m \in M^e_n} pt_{j,t,n,m} X_{j,n,m}$$

$$\left(j \in J; t \in T : j,t \in T^j_{j,t}; n = 2,\ldots,N\right) \tag{7}$$

Before the assigned tour of an order to the subsequent production facility starts the order can be stored after it passed the last production level.

$$T^{hv}_j \ge T^s_v - T^c_{j,n} - M\left(1 - A_{j,v}\right) \quad \left(j \in J; n = N; v \in V\right) \tag{8}$$

In the case that a tour is conducted the tour starts at the considered production facility and terminates at the subsequent production facility.

$$\sum_{i' \in I^S_i} Z_{v,i,i'} = O_v \quad \left(i \in I^D; v \in V\right) \tag{9}$$

$$\sum_{\substack{i \in I: \\ i' \in I^S_i}} Z_{v,i,i'} = O_v \quad \left(i' \in I^{SF}; v \in V\right) \tag{10}$$

The continuity of a tour between the considered production facility and the assigned subsequent production facility is given by equation 11.

$$\sum_{\substack{i \in I: \\ h \in I^S_i}} Z_{v,i,h} - \sum_{i' \in I^S_h} Z_{v,h,i'} = 0 \quad \left(h \in I \setminus I^D \wedge I^{SF}; v \in V\right) \tag{11}$$

Each order is assigned to one tour; partial deliveries are not allowed. A set of pre-given orders and transportation vehicles is already assigned by the results of the previous scheduling.

$$\sum_{v \in V} A_{j,v} = 1 \quad \left(j \in J\right) \tag{12}$$

$$A_{j,v} = 1 \quad \left(j \in J; v \in V : j, v \in L^{tour}_{j,v}\right) \tag{13}$$

A tour can depart from the considered production facility as soon as all assigned orders are manufactured and the transportation device is available. Furthermore the departure time for a not conducted tour equals zero.

$$T_v^s \geq T_{j,n}^c - M\left(1 - A_{j,v}\right) \qquad \left(j \in J; n = N; v \in V\right) \tag{14}$$

$$T_v^s \geq t_v^{av} - M\left(1 - A_{j,v}\right) \qquad \left(j \in J; v \in V\right) \tag{15}$$

$$T_v^s \leq O_v M \qquad \left(v \in V\right) \tag{16}$$

A lower bound for the arrival time of a tour at the first location is given by the departure time from the depot and the minimal required travel time between the locations.

$$T_v^s + d_{i,i'} - M\left(1 - Z_{v,i,i'}\right) \leq T_{v,i'}^a \qquad \left(i \in I^D; i' \in I : i' \in I_i^s; v \in V\right) \tag{17}$$

Equation 15 ensures that the arrival time at a consecutive location of a tour is greater than the sum of preceding arrival time and the minimal required travel time.

$$T_{v,i}^a + d_{i,i'} - M\left(1 - Z_{v,i,i'}\right) \leq T_{v,i'}^a \qquad \left(i, i' \in I \setminus I^D : i' \in I_i^s; v \in V\right) \tag{18}$$

In the case that a location is not part of the tour the arrival time equals zero.

$$\sum_{i' \in I : i \in I_{i'}^s} Z_{v,i',i} M \geq T_{v,i}^a \qquad \left(i \in I; v \in V\right) \tag{19}$$

Each tour has a limited transportation capacity, which cannot be exceeded by the assigned orders.

$$\sum_j A_{j,v} r_j \leq \bar{r}_v \qquad \left(v \in V\right) \tag{20}$$

In the case that at least one order is assigned to a tour the tour is conducted.

$$\sum_{j \in J} A_{j,v} \leq O_v M \qquad \left(v \in V\right) \tag{21}$$

The duration of a tour is greater than zero in the case that the tour is conducted.

$$T_v^{dv} \geq T_{v,i}^a - T_v^s - M\left(1 - O_v\right) \qquad \left(i \in I^{SF}; v \in V\right) \tag{22}$$

Each order has a desired delivery date. The delivery of an order cannot be early but late.

$$T_{v,i}^a \geq t_{i,j}^{dd} - M\left(2 - A_{j,v} - O_v\right) \qquad \left(i \in I^{SF}; j \in J; v \in V\right) \tag{23}$$

$$T_j^d \geq T_{v,i}^a - t_{i,j}^{dd} - M\left(2 - A_{j,v} - O_v\right) \qquad \left(i \in I^{SF}; j \in J; v \in V\right) \tag{24}$$

The objective function minimises the costs for delayed deliveries of the orders to the subsequent production facility, the processing and storage costs of orders and as well the fixed and variable costs of each conducted tour.

$$\begin{aligned} Min. \quad & \sum_{j \in J} T_j^d c_j^d + \sum_{j \in J} \sum_{\substack{t \in T: \\ j,t \in T_{j,t}^j}} \sum_{n \in N} \sum_{m \in M_n^e} X_{j,t,n,m} c_{j,n,m}^p \\ & + \sum_{j \in J} \left(T_j^h + T_j^{hv} + \sum_{n \in N} T_{j,n-1,n}^{hp} \right) c^h + \sum_{v \in V} \left(O_v c^{fv} + T_v^{dv} c^{dv} \right) \end{aligned} \tag{25}$$

4. COMPUTATIONAL ANALYSIS OF THE ADAPTED PTSP

The limitations of the formulated mathematical program for the integrated production and transportation scheduling problem will be identified on this section. Therefore a test scenario is set up in 4.1 and the obtained results are shown in 4.2.

4.1. Test case

The test case consists of two production facilities in Santa Catarina (Brazil). The considered facility is located in Chapecó and ships orders of intermediate products to the subsequent production facility in Joinville. A level production process, which was described by Scholz-Reiter et al. (2005), is carried out in the production facility in Chapecó. The structure of the material flow within the production facility and the structure of the transportation network are shown in Figure 2.

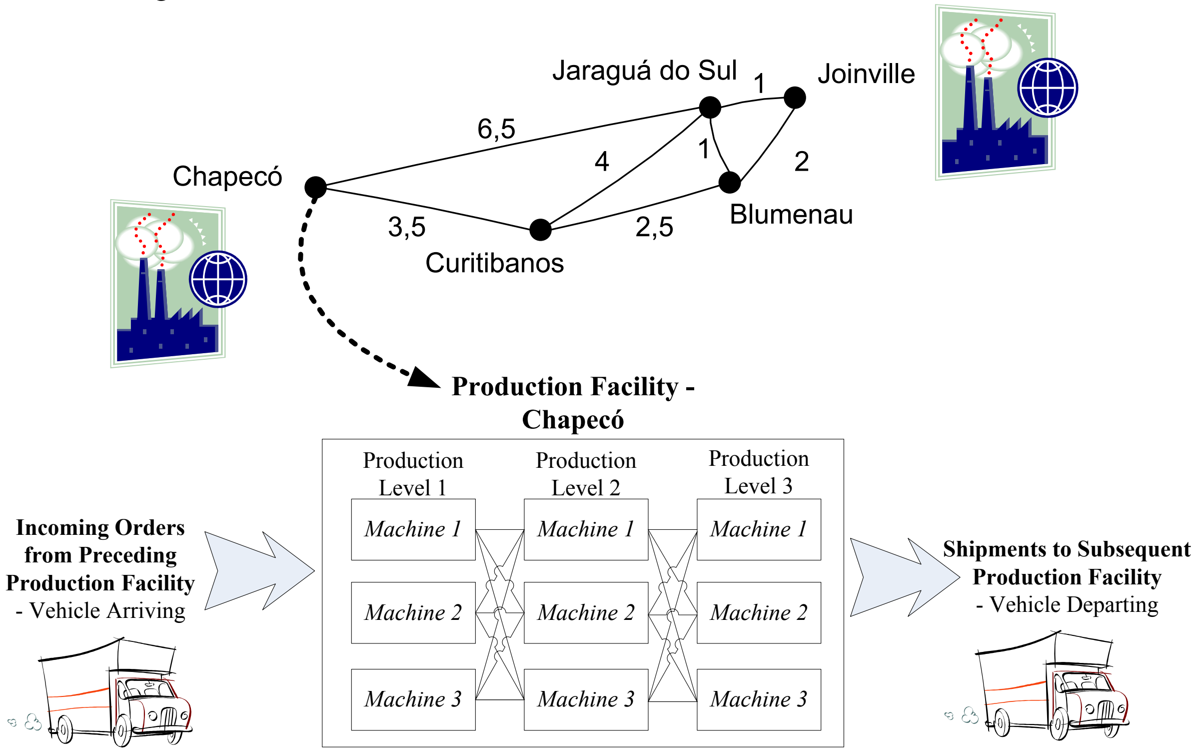

Figure 2: Structure of test scenario

The edges of the transportation network are weighted with the required travelling time of the transportation devices between the locations of the network.

4.2. Computational results

The proposed mathematical formulation of the integrated production and transportation scheduling problem has been implemented in GAMS 22.8. For simplicity all costs are in general chosen to be 1. The processing times of the three different order types for each machine are given by Scholz-Reiter et al. 2005. Processing costs are assumed to be one per required time unit of manufacturing. In the case that a tour is conducted fixed costs of 10 and costs of 1 per time unit occur. Every delayed delivery is charged by costs of 1 per delayed time unit. The required transportation capacity is assumed to be 1 for all orders. Each transportation device has a maximal transportation capacity of 5 units. The considered test instances comprise maximal five transportation devices that arrive at the following points in time: 2, 10, 18, 26 and 34. At the same point in time new orders become available for the processing. The due dates for the delivery of orders to the subsequent production facility depend on the date of provision of the orders at the planning entity and are given by the following points in time: 15.5, 25, 30, 45 and 60.

Since, the mathematical formulation is a mixed integer problem (MIP) the instances could be solved by CPLEX 11. The computation was carried out on a 2.67GHz quad-core computer with 4GB of RAM in a concurrent mode of CPLEX with four threads. The results for the test instances are given by table 1.

Transportation devices	Orders	Gap to optimal solution
1	3	0,00%
1	5	0,00%
2	7	0,00%
2	10	30,72%
3	13	38,99%
3	15	18,65%
4	17	34,16%
4	20	31,92%
5	23	32,47%
5	25	30,67%

Table 1: Gap to the optimal solution after 600 seconds

The table shows the relative gap between the best integer solution and the best node remaining after 600 seconds. For very small instances the optimal solution can be obtained within this time. Hence, by increasing the number of orders and transportation devices the need for a heuristic that is able to solve larger instances with good results is shown.

5. CONCLUSIONS AND FUTURE RESEARCH

This research focused on a framework for the informational integration of production and transport systems along global supply chains. This framework will pave the way toward modelling and analysing informational integration concepts and methods. On the long-term, a heuristic for the scheduling of production and transportation processes will be proposed. In the present paper, as first steps on this direction, a mathematical program for the planning tasks of a single entity has been formulated and tested.

Production scheduling is adapted to a flow-shop with several production levels that contain multiple machines and an open vehicle routing formulation is employed for the transportation scheduling. Moreover, the proposed formulation takes dynamic changing capabilities of the transportations system into account. Obtained results and the limited size of computationally manageable scenarios are both the motivation and starting point for the development of forthcoming heuristic. Current results will act as benchmark for the forthcoming heuristic.

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