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Simulation-based Analysis of Integrated Production and Transport Scheduling

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Abstract

Production and transport scheduling are mostly carried out sequentially due to their complexity and current lack of appropriate heuristics for supporting a desirable integration on the operational level. Especially when oscillations occur, the unbalanced and unstable integration of production and transport systems weaken the competitiveness of supply chains. In this paper, an approach for the integration of production and transport logistics in global supply chains is analysed using a simulation model. The approach is based on a generic framework where the supply chain is structured into a chain of operational planning entities. The test case comprises one original equipment manufacturer and two supplier tiers, as well as corresponding inter-facility transport operations and delivery to customers. This formulation can be applied on a rolling time horizon and takes changing capabilities into account. It was possible to identify that the integrated scheduling can handle oscillations in the production and transport processes by constantly checking the amount of time spent to process and deliver the order. The more frequent this checking occurs, the less time it will take to eliminate the discrepancies. The results also indicate that the proposed integrative approach outperforms the sequential one in dynamic situations. This means that it could help absorb disturbances originated in production and transport systems and therefore sustain the performance of global supply chains through time.

Keywords: Production Scheduling; Transport Planning; Modelling and Simulation of Supply Chains; Global Supply Chains; Logistics

1 Introduction

Production and transport scheduling are mostly carried out sequentially due to their complexity and current lack of appropriate heuristics for supporting a desirable integration on the operational level. The unbalanced and unstable integration of manufacturing and transport systems weaken the competitiveness of supply chains. Especially in dynamic situations and environments, production and transport systems must be properly integrated so that efficiency, responsiveness, and flexibility can be achieved and sustained (Scholz-Reiter et al., 2010). Indeed, local decisions cannot only depend on the efficiency of the individual processes at different locations, but rather take into account the behaviour of linked decision systems.

Sequential and hierarchical schemes for production scheduling and transport planning have been deployed with consistent performance for stable surroundings. Nevertheless, when dealing with dynamic environments – like the context in which global supply chains are inserted –, integrative schemes are necessary. Recent approaches for the integration of production and transport systems do not consider current capabilities, level of utilisation of resources, and transit-/lead-times (for a comprehensive review please refer to Scholz-Reiter et al., 2009). Resources and their employment level have to be better considered in production and transport systems so that decision making is enhanced.

In this paper, an approach for the integration of production and transport logistics in global supply chains is analysed using a simulation model. The approach is based on a generic framework where the supply chain is structured into a chain of operational planning entities (Scholz-Reiter et al., 2010). The test case comprises one original equipment manufacturer and supplier tiers, as well as the inter-facility transport

and the delivery to customers. The facilities of the referred suppliers and original equipment manufacturer are located in different continents, wherefore maritime is considered in the simulation model. The paper is structured as follows: section 2 reviews the relevant literature. The computational simulation-based analysis is presented and implemented in Section 3. The paper ends with conclusions and potential implications.

2 Literature Review

The problem of coordinating supply chain stages can be handled by a monolithic (central) approach, wherein the schedules are determined simultaneously, or by a hierarchical and sequential approach (Sawik, 2009). The central approach is usually not practicable in real-world situations, due to unfeasible requirements in terms of information availability and communication capabilities.

Even though sophisticated heuristic approaches (e.g. Wang and Cheng, 2009; Lin et al., 2008; Huang and Yang, 2008; Valente and Alves, 2007; Park, 2001; Raa and Aghezzaf, 2008; Herer and Levy, 1997; Cheung et al., 2008; Hwang, 2005) achieved exceptional results in handling isolated scheduling tasks, either production or transport, they are not able to materialise the competitiveness obtained by a combined view of production and transport systems. By utilising the combined flexibility of both systems, challenges triggered by a dynamic changing environment (e.g. perturbations) can be better handled. Therefore, an integrated alignment of production and transport scheduling at the operational level holds a great potential for strengthening the competitiveness of supply chains (Scholz-Reiter et al., 2010).

The problem of balancing the production and delivery scheduling in such a way that there is no backlog and that production, inventory, and distribution costs are minimised is addressed by Pundoor and Chen (2009). Li et al. (2008) studied a coordinated scheduling problem of parallel machine assembly and multi-destination transport in a make-to-order supply chain. Their approach decomposes the overall problem into a parallel machine scheduling sub-problem and a 3PL (third-party logistic provider) transport sub-problem. By means of computational and mathematical analysis, the 3PL transport problem is shown to be NP-complete; therefore, heuristic algorithms are proposed to solve the parallel machine assembly scheduling problem.

Centralised solutions for the production scheduling and transport planning processes along supply chains are not practically applicable, due to overwhelming eyesight and communication requirements. On the operational level, these processes are currently carried out sequentially due to their complexity and current lack of appropriate heuristics for supporting a desirable integration. Considering that 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 schemes on the operational level (Chen and Vairaktarrakis, 2005), a generic approach for the integration of production scheduling and transport planning in supply chains was proposed by Scholz-Reiter et al. (2010). This generic approach embraces a chain of operational planning entities that perform the PTSP as well as a mechanism for supporting the alignment between these entities.

Supply chains are composed by a chain of production stages, starting at the suppliers of raw material, followed by several production facilities, and ending at the OEM (Original Equipment Manufacturer). These production stages, as well as the final customers, are linked by transport systems. The proposed operational planning entities comprise the production scheduling and transport planning of a facility along the supply chain (Figure 1).

Therefore, one entity carries out the scheduling for a production facility and associated transport to either the next production facility or final customers. The scheduling tasks of the entities are aligned by production / delivery orders. The scheduling of the orders is based on the order delivery dates, which are provided by upstream planning. Furthermore, in order to ensure the delivery of orders, the entities have the flexibility to contract external production processing or transport capacity. Each entity strives to

achieve a certain service level in regard to the in-time delivery of orders and to minimise the costs for production and transport (Scholz-Reiter et al., 2009).

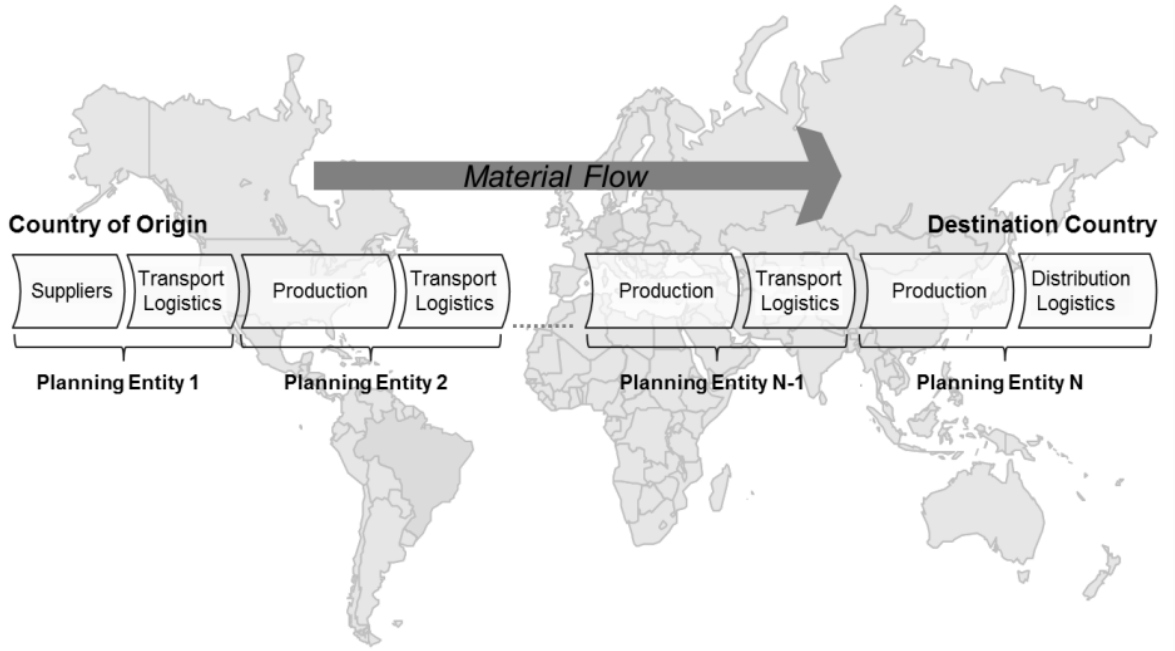

Figure 1: Chain of planning entities on the operational level of a generic global supply chain (Scholz-Reiter et al., 2009)

A scheduling scheme at the operational level needs to be run in a successive way. This is motivated by the arrival of new orders, disturbances, as well as variations of current capabilities within the production and transport systems. In the intervening time between iterations, capabilities, and the employment level of involved production and transport system may change due to either planned events like maintenance of a machine or a transport device, as well as disturbances like the breakdown of a machine, or the flooding of a road. Therefore, the iteration time should be reduced in order to maximise the adaptability of the supply chain to dynamics. With the acceleration of these feedback loops, an on-line optimisation mechanism for supply chain priorities will emerge.

The analysis of complex systems like global supply chains demands the employment of proper methods. Here, the computational experiment for such analysis will be implemented using a discrete event simulation model. The use of discrete event simulation, due to its flexibility, is more efficient for developing evaluation systems in comparison to traditional, less automated tools (Spedding and Sun, 1999). Another advantage of this method is related to its ability to deal with problems which cannot be solved through standard analytical methods (Legato and Mazza, 2011). For instance, tools based on discrete-event simulation can be developed to aid decision makers in the dynamic and complex situations of supply chains (Liston *et al.*, 2007). In regard to its use, discrete event simulation is commonly used to model multi-stage production systems and then evaluate the impact of different approaches for controlling these systems (e.g. Van Volsem *et al.*, 2007). In terms of content, process and outcome, discrete event simulation models have promising uses within the broad areas of management science and operational research (Robinson, 2002).

The design of integrated processes on the operational level of supply chains is a pressing challenge for both practitioners and scientists. On the sequence, the referred integrative approach will be analysed by means of a discrete event simulation model.

3 Computational Experiment and Analysis

Usually, different departments within supply-chain partners perform the scheduling of production and transport, by making locally-bounded decisions. As a drawback, the obtained results may be locally optimal but do not pay attention to the requirements of connected systems over the supply chain. In this section, a computational experiment using a discrete event simulation model for analysing the proposed integration approach (Scholz-Reiter et al., 2009) is structured and implemented.

3.1 Model Structure

The modelled production system is based on a heterogeneous open flow-shop with several consecutive production levels. Each production level consists of three machines, which feature an order-type specific processing time and processing cost. All orders have to be processed in one machine of each production level. If all machines are highly occupied, orders can be processed externally in a comparatively longer timescale.

After the production process, the orders are assigned, through the transport, to the subsequent production facility. If at least three orders are assigned to a tour then this tour is conducted. The duration of each inter-facility transport is pre-given. All considered tours start at the production facility and end at the subsequent one (or the final customer). A new tour can be conducted as soon as a transport device becomes available. Each tour has a limited transport capacity of five units that cannot be exceeded. Disturbances affecting production or transport processes can be introduced by adjusting their capabilities. It is also possible to simulate different oscillations in market demand.

The models (Figures 2 and 3) represent production and transport execution levels of one entity within the chain of planning entities (Figure 4). Each planning entity is composed by two sub-models: the production facility and the transport path. When dealing with sequential scheduling (Figure 2), the demand $\mathbf{D_{i+1}}$ is only communicated to the stock of ready-to-delivery orders. Each piece of information contains the orderID, the orderType, as well as its due-date $\mathbf{d}$. The order due-date is calculated considering the average of transport and production lengths of the time horizon. The time when the orders should be ready to deliver is calculated considering the transport time $\mathbf{t_t}$, which is calculated by taking into account the time dispended previous tour. Sequentially, the stock of ready-to-delivery orders triggers the input of orders in the production system. The input timing is calculated considering the production time $\mathbf{t_p}$, which is calculated by taking into account the average of production lengths of the previous week. As soon as 3 orders are ready to deliver, the transport device executes the tour to the client facility. To the overseas transporter, this limit is assumed to be 700. Land transporters can carry up to 5 products, whilst ships have no such limit.

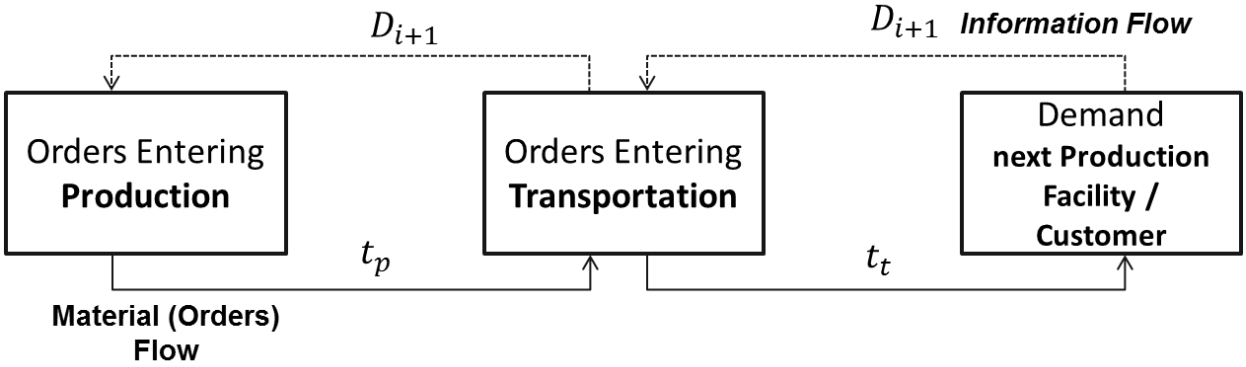

Figure 2: Model structure for one entity – Sequential scheduling set up

In the case of integrated scheduling (Figure 3), the demand $\mathbf{D_{i+1}}$ from the next facility triggers directly the input of orders in the production systems. Each piece of information contains the orderID, the orderType, as well as its due-date $\mathbf{d}$, calculated in the same way as specified for sequential scheduling. The remaining rules of transportation are identical to the sequential planning entity.

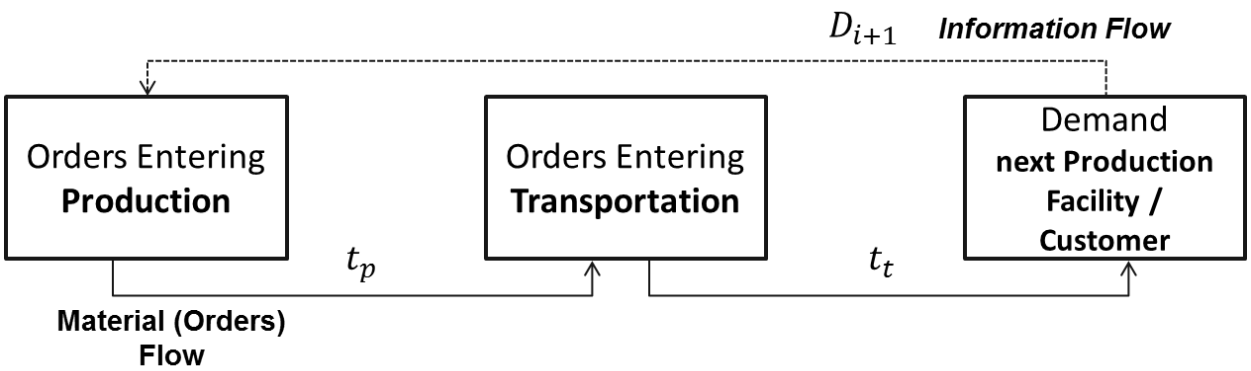

Figure 3: Model structure for one entity – Integrated scheduling set up

In both cases, early deliveries are not allowed. Both set ups described above will be employed in a test case in the next section.

3.2 Test Case

In this section both sequential and integrated scheduling models are implemented in a discrete event simulation model for a scenario with three planning entities in a global supply. The test case consists of one OEM located in Brazil and two suppliers (one in Brazil and the other one in Germany). Between the supplier in Germany and the supplier in Brazil, maritime transport is performed. The required travelling time for the maritime transport is assumed to be four weeks. A land transport occurs, between the supplier in Brazil and the OEM and it is assumed to take six hours. Finally, the transport is performed, to the final customers using land transport. This transport is assumed to take five hours.

As an illustrative disturbance, a variable time will be added to the travelling time (T_{travel}), which is the time required from the transporter to reach its destination. In order to resemble a seasonal behaviour, the variable component was chosen to be a sinusoidal function. As shown below, (1) represents the function parameters having M as mean value, V as amplitude and T as the time required to complete a whole cycle of the function. For convenience, all the times are taken in hours.

$$T_{travel}(t) = M + V\,.Sin\left(\frac{2.\pi\,.t}{T}\right) \quad (1)$$

The supplier in Germany uses ships as transporters. The estimated traveling time is four weeks, or 672 hours. However, this value could oscillate up to half a week (84 hours) upwards or downwards. The function then assumes the following values:

$$T_{t1}(t) = 672 + 84\,.Sin\left(\frac{2.\pi\,.t}{8760}\right) \quad (2)$$

The same oscillatory behaviour happens to the trucks carrying the orders from the supplier in Brazil. With a mean travel time of six hours, it varies from two to ten hours depending on the time along the year.

$$T_{t2}(t) = 6 + 4\,.Sin\left(\frac{2.\pi\,.t}{8760}\right) \quad (3)$$

A production process, which was described by Scholz-Reiter et al. (2005), is carried out at each production facility. The structure of the material flow within the production facility, as well as the structure of the inter-facility transport, are shown in Figure 4. The test case will be run along a year.

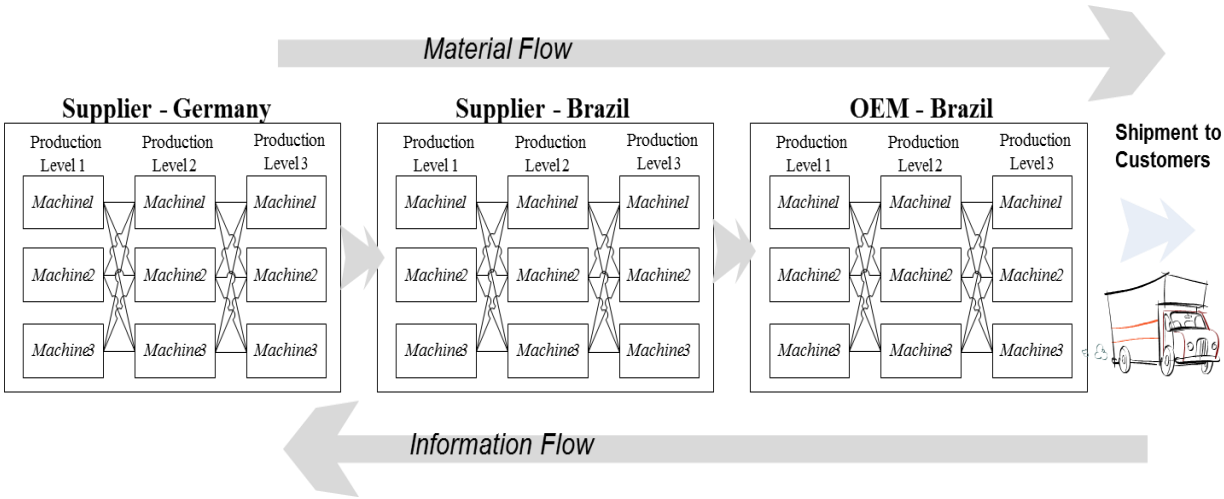

Figure 4: Structure of the test case scenario: 3 planning entities (production +transport processes) connected in a global supply chain

For the sake of 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). The processing costs are proportional to the required processing time.

External processing of orders triggers costs of 12 (production and transport). Externally processed orders return directly to the finished products buffer. Each land transport device has a maximal transport capacity of 10 units. For maritime and air transport, there is no capacity limit. As soon as 5 or more units are ready, the tour is conducted.

The dynamic scenario includes transport time oscillations. The simulation model of the production and transport scheduling has been implemented in SIMIO version 3.48.6267 and the computation was carried out on a Core i7 2.8 GHz quad-core computer with 12GB of RAM. Each simulation run took about 1 minute and 20 seconds.

3.3 Results

The following Figure 5 shows the difference between due-dates and actual delivery over the weeks for the sequential set up. The horizontal axis represents the weeks (week 1 to week 52), whilst the vertical axis represents the delay (difference between due-dates and actual delivery to the final customer), for each order requested by the client, measured in hours.

A positive value means that the entity arrived late, whilst a negative value indicates an early delivery. The continuous line represents the delay when there are no oscillations in transport time. The dashed line represents the delay when time oscillations in transport time between the supplier in Germany and the supplier in Brazil are introduced.

The peaks can be interpreted as a lack of products in subsequent clients, caused by a delay to carry them overseas.

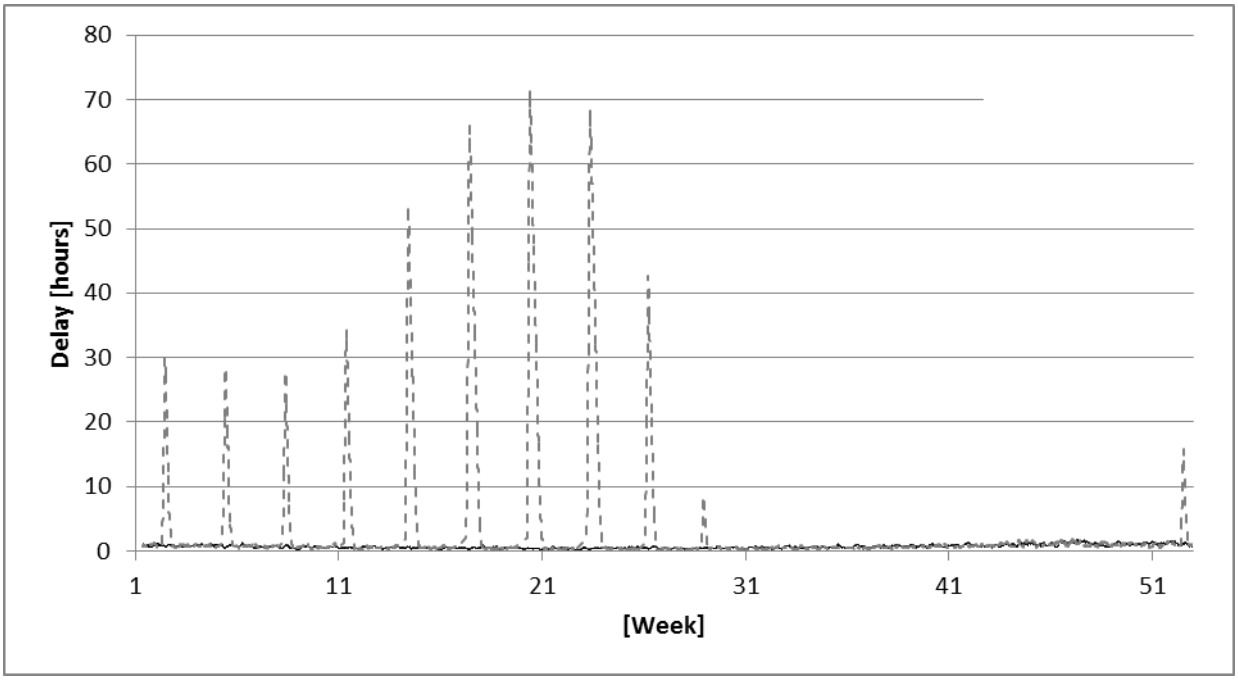

Figure 5: Delay - without oscillations (black bold line) and with oscillations (grey dashed line) introduced in the transport time between the supplier in Germany and the supplier in Brazil – Sequential scheduling set up

Likewise, the continuous line (no oscillation) and the dashed line (oscillations introduced) in Figure 6 represent the difference between due-dates and actual delivery over the weeks for the sequential set-up, when the transport time oscillation is placed in the transport between the supplier in Brazil and the OEM in Brazil.

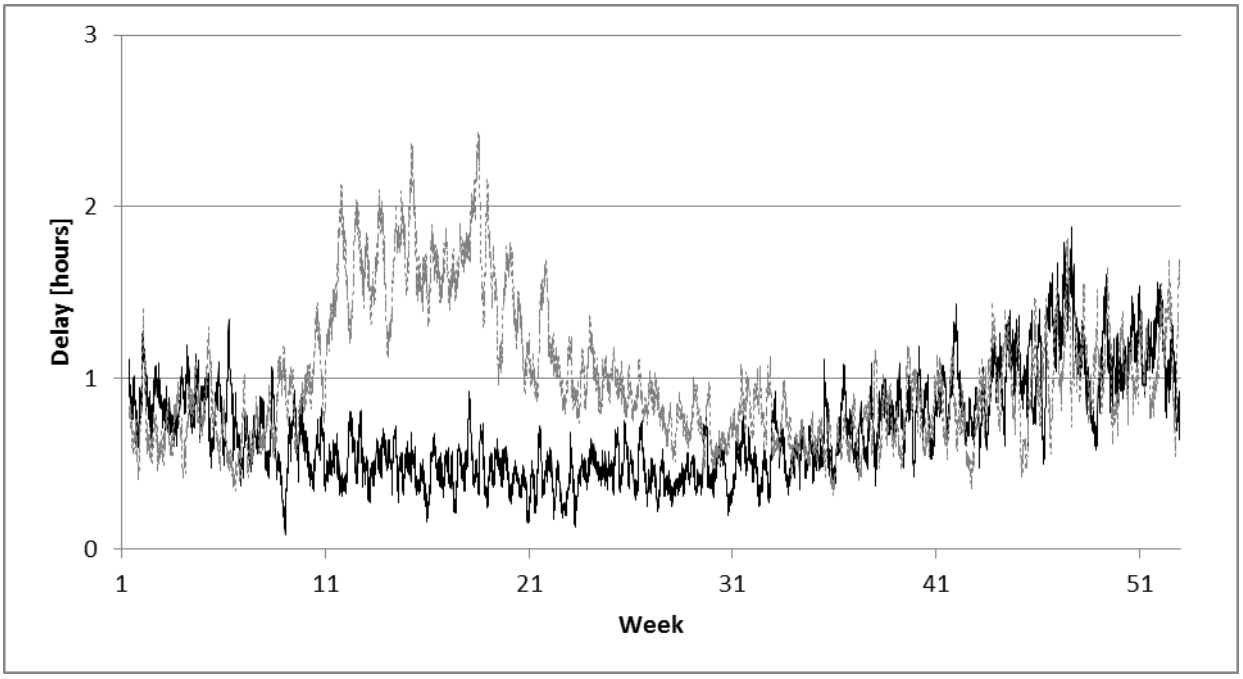

Figure 6: Delay - without oscillations (black bold line) and with oscillations (grey dashed line) introduced in the transport time between the supplier and the OEM in Brazil – Sequential scheduling set-up

For the integrated scheduling set-up, the following Figures 7 and 8 show the same scenario configuration from Figures 5 and 6, respectively.

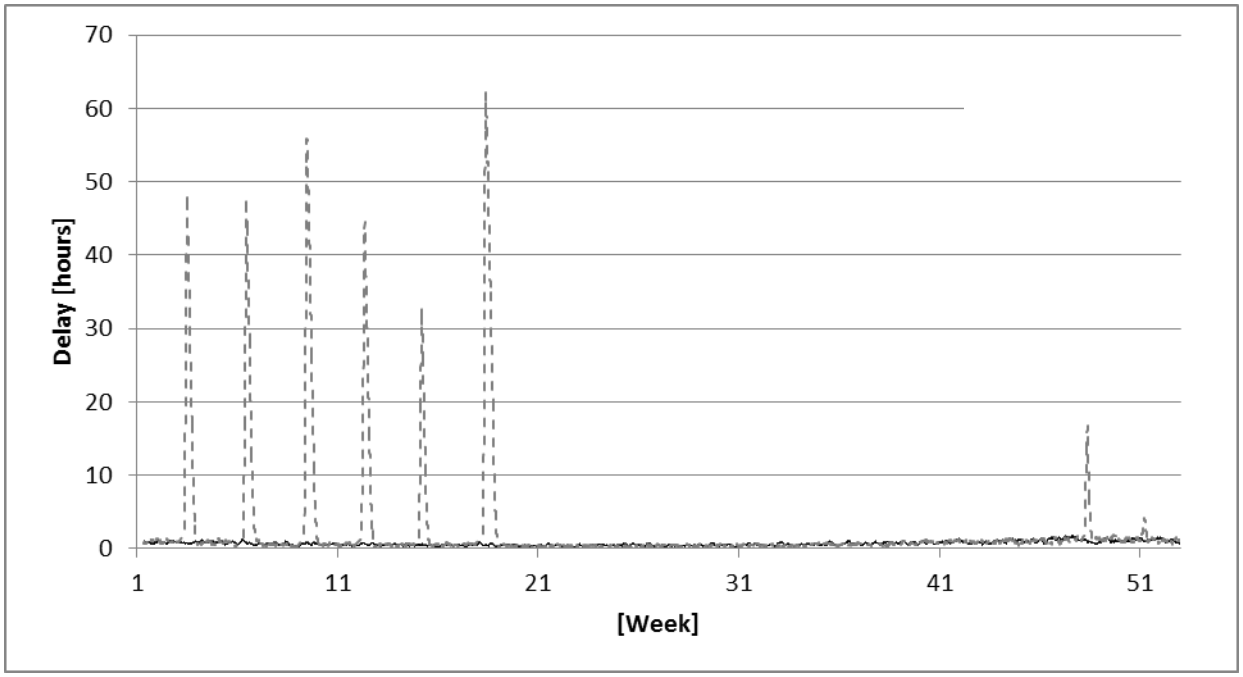

Figure 7: Delay - without oscillations (black bold line) and with oscillations (grey dashed line) introduced in the transport time between the supplier in Germany and the supplier in Brazil – Integrated scheduling set-up

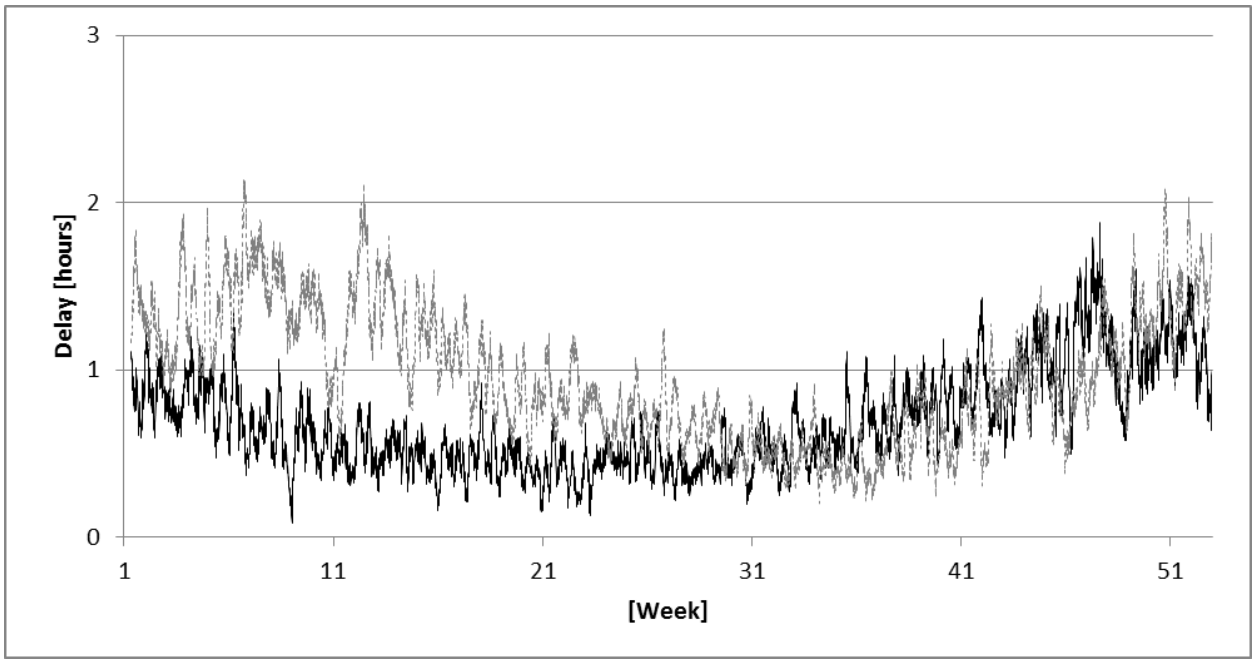

Figure 8: Delay - without oscillations (black bold line) and with oscillations (grey dashed line) introduced in the transport time between the supplier and the OEM in Brazil – Integrated scheduling set-up

The results obtained indicate that the proposed integrative approach outperforms the sequential one in dynamic situations where oscillations in transport time are considered.

3.4 Analysis

The comparative analysis of the delivery delays between the sequential and the proposed integrative approach indicate that the latter could absorb disturbances originated in production and transport processes with low reliability and/or market oscillations. These different oscillations can impair the performance of production and transport systems. Our computational analysis indicates three major findings: (i) lead-times can be shortened by properly combining the flexibilities of production and transport systems; (ii) if there is a peak on the utilisation of the production system, for instance, the available time for processing of orders, which can be delivered in short time, can be extended; and (iii) in a situation where the transport process requires more time than the anticipated, the production scheduling can be rearranged so that orders are early available for transport. Furthermore, the mean values of due dates utilised in the upstream planning can be reduced, by leaning required buffering times.

4 Discussion and Implications

In this paper, we analysed by means of simulation an approach for the integration of production and transport scheduling that fosters a sustainable management of production and transport systems along whole supply chains (Scholz-Reiter et al., 2010). A simulation model for the case of inter-facility transport along a global supply chain was formulated. This formulation can be applied to a rolling time horizon and takes dynamic changing capabilities of the transport into account. It was possible to notice that the integrated scheduling can handle oscillations in the production and transport process, by constantly checking the amount of time spent to process and deliver the order. The more frequent this checking occurs, the less time it will take to eliminate the discrepancies.

The following topics of research could be pursued in the future: development and implementation of more elaborated heuristic decision rules triggering the production and transport processing; development of quasi-real-time scheduling methodologies; pursuing empirical descriptive research in different real-world scenarios.

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