SIMULATION-BASED ANALYSIS OF THE INTEGRATION BETWEEN PRODUCTION AND INTER-FACILITY TRANSPORTATION SCHEDULING

Enzo Morosini Frazzon
Joarez Pintarelli Jr.
Gustavo Stelzner
Antônio G. N. Novaes
Industrial and Systems Engineering Department
Federal University of Santa Catarina (UFSC), Brazil

ABSTRACT
The purpose of this paper is to introduce an approach for the integration of production and transportation scheduling in supply chains and to compare its performance with the sequential procedure currently employed in Advanced Planning Systems using simulation. The major findings demonstrate that the proposed integrative approach outperforms the sequential one in the absorption of perturbations that can delay the production or delivery of the orders.

RESUMO
O objetivo deste artigo foi determinar o desempenho, em termos do cumprimento dos prazos de entrega, de uma abordagem integrada para a programação da produção e dos transportes e compará-lo com o obtido por meio da abordagem sequencial atualmente utilizada em Sistema de Planejamento Avançados (*Advanced Planning Systems*). A comparação foi desenvolvida com o uso de ferramentas de simulação. Os resultados obtidos demonstram que a abordagem integrada proposta obtém melhores resultados em comparação com a sequencial na absorção de perturbações que podem atrasar a produção ou a entrega de pedidos.

1. INTRODUCTION

Production and transportation 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 transportation systems may weaken the competiveness of supply chains. Especially within dynamic environments, production and transportation systems must be properly integrated so that efficiency, responsiveness and flexibility could 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.

In this paper an approach for the integration of production scheduling and inter-facility transportation is analysed using a simulation model. The approach comprises one original equipment manufacturer as well as subsequent inter-facility transportation. 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 paper is structured as follows. Section 2 reviews relevant literature. The simulation model for the analysis of the approach for the integrated production and transportation scheduling problem (PTSP) is addressed in Section 3. The computational simulation-based analysis is presented and tested in Section 4. The paper ends with conclusions and potential implications.

2. LITERATURE REVIEW

Sequential and hierarchical schemes for production scheduling and transportation planning have been deployed with consistent performance for stable surroundings. When dealing with dynamic environments, integrative schemes are necessary. Recent approaches for the integration of production and transportation systems do not consider current capabilities, level of utilisation of resources and transit-/lead-times (Scholz-Reiter et al., 2009). This limitation has special relevance in supply chains, where components of production and logistics must be properly integrated so that efficiency, responsiveness and flexibility could be achieved and sustained (Scholz-Reiter et al., 2010).

2.1. Production and Transportation Scheduling Problem

Resources and their employment level have to be better considered in production and transportation systems so that decision making in the dynamic and competitive environment of supply chains is enhanced. The problem of coordinating supply chain stages can be handled by a monolithic (central) approach, where the schedules are determined simultaneously, or 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, 2009a; 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 transportation – they are not able to materialise the competitiveness obtained by a combined view of production and transportation 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 transportation scheduling at the operational level holds a great potential for strengthening the competitiveness of supply chains (Scholz-Reiter et al., 2010).

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 simultaneously. PTSP is normally motivated by perishables products so that production and transportation of these short-lifespan products are synchronised. Furthermore, the classic PTSP focuses on constraints connected rather to production capacities than to transportation times and costs (Hochbaum and Hong, 1996; Tuy et al., 1996; Sarmiento and Nagi, 1999). These approaches often assume the transportation to be instantaneous and do not address the routing of the transportation vehicles. The nature of PTSP’s leads to a mathematical program that is NP-hard in the strong sense. 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.

Several insights and concepts for the integration of production and transportation have been developed in the recent years (e.g. Cohen and Lee, 1988; Chandra and Fisher, 1994; Haham and Yano, 1995; Thomas and Griffini, 1996; Fumero and Vercellis, 1999; Sahin et al., 2008). But most of these concepts focus either on the strategic or tactical level (Chen, 2004). Papers that deal with detailed schedules for the transportation can be classified according to the objectives of applied mathematical programs and heuristics. One group only considers the lead time for production and transportation of orders (e.g. Potts, 1980; Woeginger, 1994 and 1998; Lee and Chen, 2001; Hall et al., 2001; Geismar et al., 2008). The second group takes lead times and associated costs into account (e.g. Hermann and Lee, 1993; Chen, 1996; Cheng et al., 1996; Wang and Cheng, 2000; Hall and Potts, 2003; De Matta and Miller, 2004; Chen and Vairaktarakis, 2005; Pundoor and Chen, 2005; Chen and Pundoor, 2006; Stecke and Zhao, 2007). Although the determination of detailed schedules for the production and transportation represents a good achievement, the routing of the utilised transportation vehicles has to be properly considered. This challenge is only addressed by a few authors (e.g. Li et al., 2005; Geismar et al., 2008).

The problem of balancing the production and delivery scheduling so that there is no backlog and production, inventory and distribution costs are minimise is addressed by Pundoor and Chen (2009). Li et al. (2008) studied a coordinated scheduling problem of parallel machine assembly and multi-destination transportation 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) transportation sub-problem. By means of computational and mathematical analysis, the 3PL transportation problem is shown to be NP-complete, therefore heuristic algorithms are proposed to solve the parallel machine assembly scheduling problem.

In general the above literature is dedicated to be applicable for special settings and therefore no generic approach for the integration of production scheduling and transportation planning along supply chains exists. This means that they are not suitable for a generic and fully integrated structure of a supply chain; do not consider perturbations or a rolling time horizon. Furthermore, most of them do not analyse routing decisions, which have to be part of an advanced PTSP approach.

2.2. Integration and Performance of Supply Chains

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. The idea of managing the integrated supply chain and transforming it into a highly agile and adaptive network certainly provides an appealing vision for managers (Surana et al., 2005). Successful supply chain integration depends on the ability of partners to collaborate so that information is shared. In particular, production and transportation systems must exchange information so that plans and schedules are aligned. Scheduling tasks become more complicated because legally independent companies are constantly interacting in situations of information asymmetry. Information asymmetry arises due to fact that each legally independent partner usually owns a set of private information (e.g. costs, level of utilisation) that the partner is, in general, not willing to share (Dudek, 2004).

The establishment of collaborative relationships among supply-chain partners is a requisite for iteratively aligning independent entities in supply chains. Nevertheless, approaches for structuring this collaboration still lack the ability to be implemented (Scholz-Reiter et al., 2010). Specifically in regard to production and transportation systems, a comprehensive scheme for handling this integration on the operational level does not exist. Building scheduling approaches that integrate supply, production and distribution and could also deal with various machine processing environments embodies an important research challenge (Wang and Cheng, 2009b).

2.3. Integrated Approach for PTSP's in Supply Chains

Centralised solutions for the production scheduling and transportation 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 transportation planning in supply chains has been 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. These production stages as well as the final customers are linked by transportation systems. The proposed operational planning entities comprise the production scheduling and transportation planning of one facility along the supply chain (Figure 1).

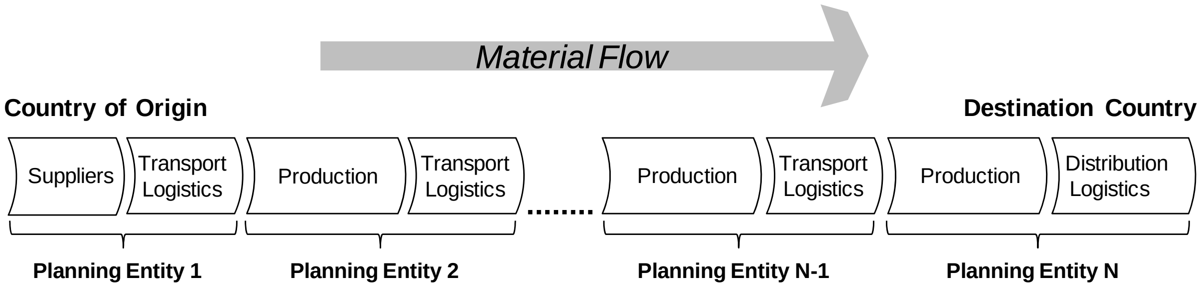

Figure 1 – Chain of planning entities on the operational level (Scholz-Reiter et al., 2009)

Therefore, one entity carries out the scheduling for one production facility and associated transportation 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 transportation 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 transportation (Scholz-Reiter et al., 2009).

A scheduling scheme at the operational level needs to be run in successive way. This is motivated by the arrival of new orders, perturbations as well as variations of current capabilities within the production and transportation systems. In the intervening time between iterations, capabilities and employment level of involved production and transportation system may change due to either planned events like maintenance of a machine or a transportation device as well as perturbations 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 design of integrated processes on the operational level of supply chains is a pressing challenge for both practitioners and scientists. The concept answers to the demand of new approaches that deliver effective integration and competitiveness gains to the supply chains. The generic approach embodies an overall concept applicable to different industries. On the sequence, a simulation model for analysing this integrative approach will be proposed, formalised and tested in a specific test scenario (Section 4).

4. COMPUTATIONAL EXPERIMENT AND ANALYSIS

Different departments within supply-chain partners usually perform the scheduling of production and transportation 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 simulation model for analysing the proposed integration approach (Scholz-Reiter et al., 2009) is presented.

4.1. Model Structure

The applied production scheduling is based on a heterogeneous open flow-shop with several consecutive production levels. Each production level consists of several machines, which feature an order-type specific processing time and processing cost. All orders have to be processed at one machine at each production level. Furthermore, orders can be processed externally in a comparatively long time and at a high cost.

After the production process the orders are assigned to tours for the transportation to the subsequent production facility. If at least five orders are assigned to a tour this tour is conducted. In this case fixed and variable costs occur. The variable costs depend on the duration of the tour. The duration of different candidate paths are pre-given. All considered tours start at the production facility and end at the subsequent one. In the sequence, the vehicles return. A new tour can be conducted as soon as a transportation device becomes available. Each tour has a limited transportation capacity that cannot be exceeded. Perturbations affecting production or transportation processes can be introduced by adjusting the reliability of model elements and the dynamicity of market demand.

The model represents production and transportation execution level of one entity within the chain of planning entities (see Figure 1). The model is structured as a discrete-event simulation model with two sub-models: the production facility and the transportation network.

When dealing with sequential scheduling (Figure 2), the demand D_{i+1} is communicated to the *stock* of ready-to-delivery orders. Each piece of information contains the *orderID*, the *orderType* as well as its due-date d. The order due-date is distributed equally along the week and is calculated considering the average of transportation and production lengths of the last week as well as the demand of the current week. The timing when the orders should be ready to deliver is calculated considering the transportation time t_t calculated taking into account the average of transportation lengths of orders shipped in the previous week. *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 t_p calculated taking into account the average of production lengths of the previous week. As soon as 5 orders are ready to deliver, the transportation device executes the transport to the client facility.

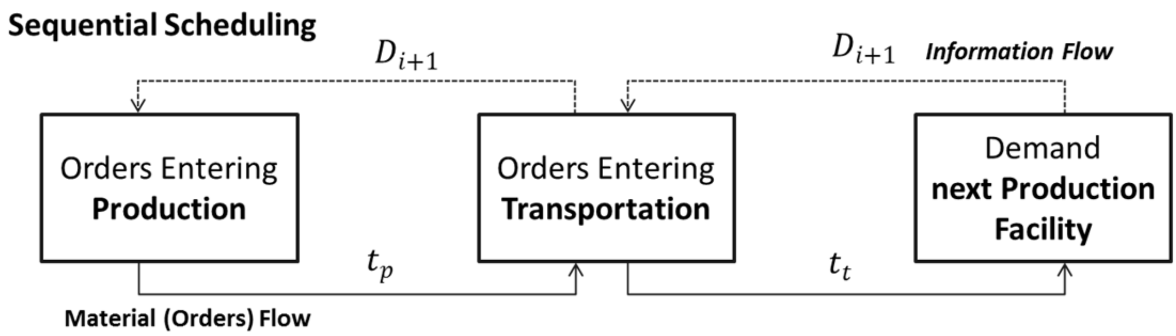

Figure 2 – Model structure – Sequential scheduling set up

In the case of integrated scheduling (Figure 3), the demand 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 d calculated in the same way as specified for sequential squeduling. The input timing is calculated considering the production t_p *and* transportation duration t_t calculated taking into account the average of transportation and production lengths of the orders produced and transported in the last week. As soon as 5 orders are ready to deliver, the transportation device executes the transport to the client facility.

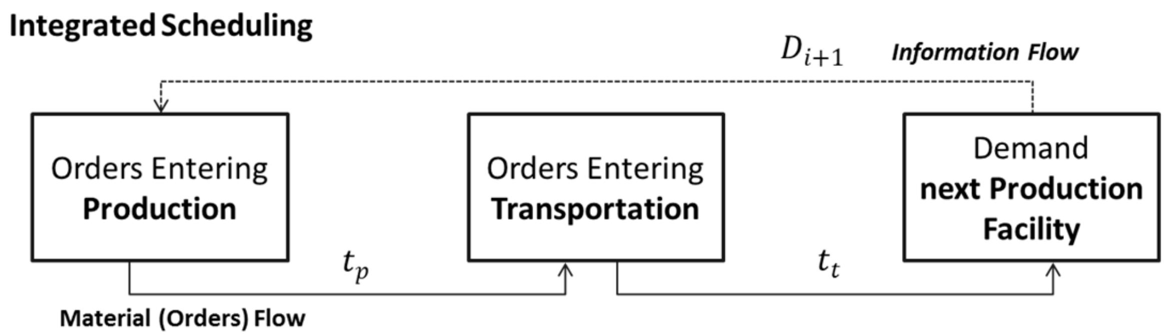

Figure 3 – Model structure – Integrated scheduling set up

In both cases, early deliveries are allowed and the orders are sent to the input of production facility at least 24 hours before the first order of the week enter at the production level. Both set ups described above will be employed in a test case in the next section.

4.2. Test Case

In this section the simulation model for one planning entity within a supply chain is applied to a test case in Germany. The test case consists of one production facility located in Kassel. The considered factory ships orders of intermediate products to the subsequent production facility in Dresden.

A production process, which was described by Scholz-Reiter et al. (2005), is carried out at the factory in Kassel. The structure of the material flow within the production facility and the structure of the transportation network are shown in Figure 4. The edges of the transportation network are weighted with the required travelling time between the locations of the network.

The test case will be run along a year.

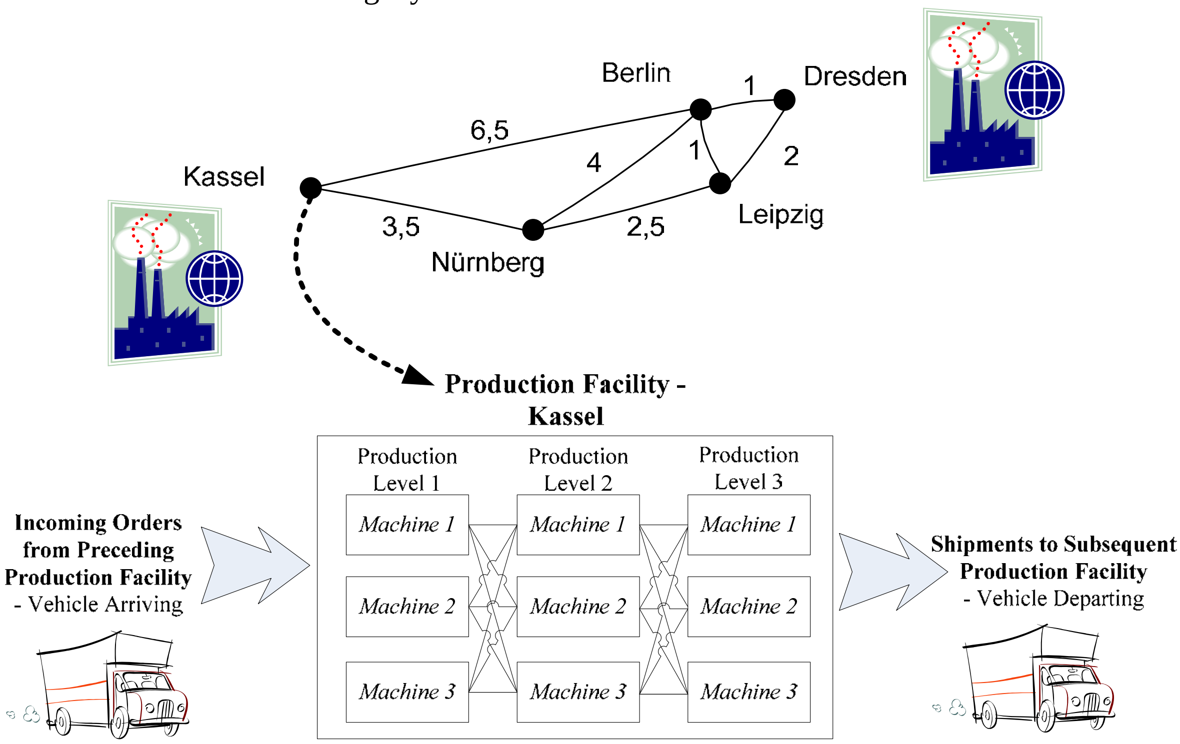

Figure 4 – Structure of the test case scenario

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). The processing costs are proportional to the required time of processing. In the case that a tour is conducted a fixed cost of 10 occurs. External processing of orders triggers costs of 12 (production and transportation). Externally processed orders return directly to the finished products buffer. Each transportation device has a maximal transportation capacity of 10 units. The considered test instances can comprise up to five transportation devices. As soon as 5 or more units are ready the tour is conducted.

The following scenarios will be considered in the simulation:

I. Sequential scheduling and dynamic situation (low reliability of production and transportation processes and market oscillations);
II. Sequential and static situation (high reliability of production and transportation processes and steady market);
III. Integrated scheduling and dynamic situation (low reliability of production and transportation processes and market oscillations);
IV. Integrated and static situation (high reliability of production and transportation processes and steady market).

In the dynamic situation, a disturbance is introduced at the half of the fifth week and last for 1 month. The disturbance in the transportation process is represented by an increase in the travel time of 6.5 hours, from 7.5 hours to 14 hours. The simulation model of the production and transportation 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.

4.3. Results

The following Figure 5 and 6 show the difference between due-dates and actual delivery over the weeks. The horizontal axis represents the weeks (week 3 to week 25) and the vertical axis represents the delay (difference between due-dates and actual delivery) for each order requested by the client, measured in hours. A positive value means that the entity arrived late, and a negative value indicates an early delivery. The graphic below (Figure 5) shows, for the sequential scheduling set up, the moving average of the last 50 deliveries. The grey line represents the delay over the weeks in the dynamic situation. The black line embodies the behaviour of the system in the static situation (Scenario II).

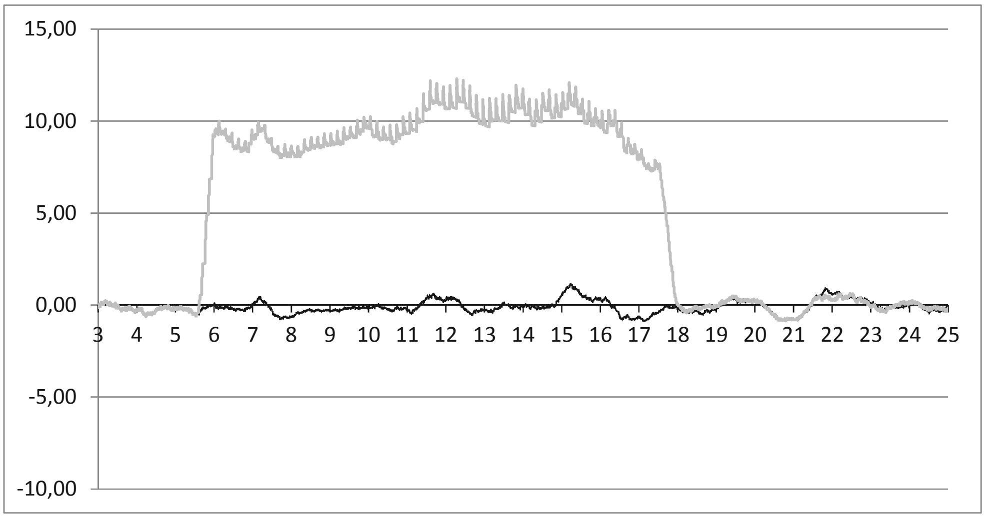

Figure 5 – Sequential scheduling: Scenario I (grey line) and Scenario II (black line)

The graphic below (Figure 6) shows, for the integrated scheduling set up, the moving average of the last 50 deliveries. The grey line represents the delay over the weeks in the dynamic situation (Scenario III). The black line embodies the behaviour of the system in the static situation (Scenario IV).

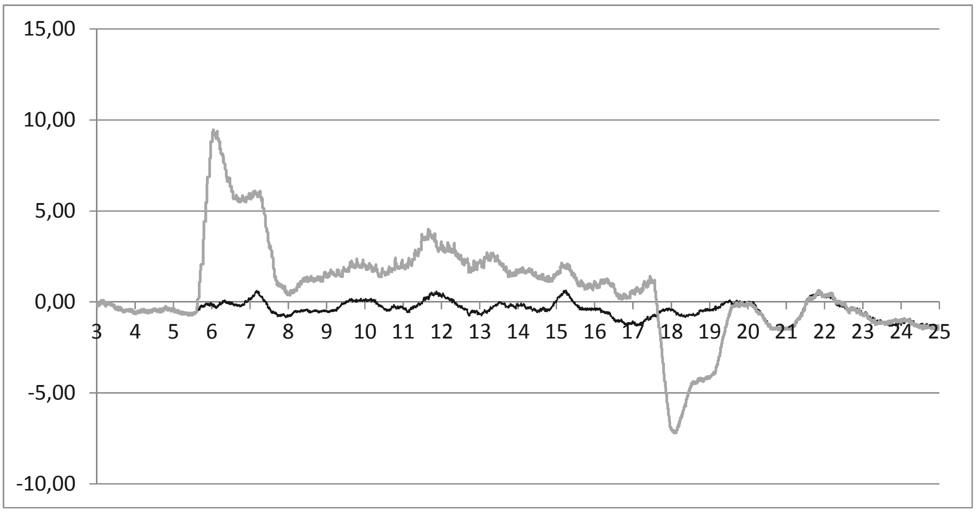

Figure 6 – Integrated Scheduling: Scenario III (grey line) and Scenario IV (black line)

4.4. Analysis

The results indicate that the proposed integrative approach outperforms the sequential one in dynamic situations. This means that it could absorb perturbations originated in production and transportation processes with low reliability and/or market oscillations that can impair the performance of production and transportation systems. Our computational analysis indicates three major findings.

- Costs can be significantly reduced and lead-times can be shortened by properly combining the flexibilities of production and transportation systems.
- For instance, if there is a peak on the utilisation of the production system, the available time for processing of orders, which can be delivered in short time, can be extended.
- In a situation where the transportation process requires more time than anticipated, the scheduling of production can be rearranged so that orders are early available for transportation. Furthermore, the mean values of due dates utilised in the upstream planning can be reduced by shortening required buffering times.

5. DISCUSSION AND IMPLICATIONS

Existing approaches for the production and transportation scheduling with capacity constraints are often not applicable for the operational management of supply chains. In this paper we analysed by means of simulation an approach for the integration of production and transportation scheduling that fosters a sustainable management of production and transportation systems along whole supply chains (Scholz-Reiter et al., 2010).

One simulation model for the case of inter-facility transportation was formulated. This formulation can be applied on a rolling time horizon and takes dynamic changing capabilities of the transportation and production into account. It was possible to identify that the integrated scheduling can handle oscillations in the production and transportation 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 transportation processing; modelling of whole supply chains, whole global supply chains and complex networks; pursuing empirical descriptive research in different real-world scenarios trying to substantiate the affirmation that “embodies an overall concept applicable to different industries” (Scholz-Reiter et al., 2010).

ACKNOWLEDGEMENTS

This research was supported by CAPES, CNPq, FINEP and DFG as part of the Brazilian-German Collaborative Research Initiative on Manufacturing Technology (BRAGECRIM). This research was also supported by a grant from Simio LLC which provided the simulation software used in the computational analysis.

REFERENCES

Chandra, P.; Fisher, M.L. (1994). Coordination of production and distribution planning. European Journal of Operational Research 72, 503-517.
Cheng, T.C.E.; Gordon, V.S.; Kovalyov, M.Y. (1996). Single machine with batch deliveries. European Journal of Operational Research, 94, 277-283.
Chen, Z.-L. (1996). Scheduling and common due date assignment with earliness-tardiness penalties and batch

delivery costs. European Journal of Operational Research, 93, 49-60.
Chen, Z.-L.; Vairaktarakis, G.L. (2005). Integrated scheduling of production and distribution operations. Management Science, 51, 614-628.
Chen, Z.-L.; Pundoor, G. (2006). Order assignment and scheduling in a supply chain. Operations Research, 54, 555-572.
Cheung, B. K.-S.; Choy, K.L.; Li, C.-L.; Shi, W.; Tang, J. (2008). Dynamic routing model and solution methods for fleet management with mobile technologies. International Journal of Production Economics, 113 (2), 694-705.
Cohen, M.A.; Lee, H.L. (1988). Strategic analysis of integrated production-distribution systems: Models and methods. Operations Research, 36, 212-228.
De Matta, R.; Miller, T. (2004). Production and inter-facility transportation scheduling for a process industry. European Journal of Operational Research, 158, 72-88.
Dudek, G. (2004). Collaborative Planning in Supply Chains. Springer, Berlin.
Fumero, F.; Vercellis, C. (1999). Synchronized development of production, inventory, and distribution schedules. Transportation Science, 33, 330-340.
Geismar, H.N.; Laporte, G.; Lei, L.; Sriskandarajah, C. (2008). The Integrated Production and Transportation Scheduling Problem for a Product with Short Lifespan. INFORMS Journal on Computing, 20/1, 21-33.
Haham, J.; Yano, C.A. (1995). The economic lot and delivery scheduling problem: Powers of two policies. Transportation Science, 29, 222-241.
Hall, N.G.; Lesaoana, M.; Potts, C.N. (2001). Scheduling with fixed delivery dates. Operations Research, 49, 134-144.
Hall, N.G.; Potts C.N. (2003). Supply chain scheduling: Batching and delivery. Operations Research, 51, 566-584.
Herer, Y. T.; Levy, R. (1997). The Metered Inventory Routing Problem, an integrative heuristic algorithm. International Journal of Production Economics, 51 (1-2), 69-81.
Herrmann, J.; Lee, C.-Y. (1993). On scheduling to minimize earliness-tardiness and batch delivery costs with a common due date. European Journal of Operational Research, 70, 272-288.
Hochbaum, D.; Hong, S.P. (1996). On the complexity of production and transportation problems. SIAM Journal on Optimization, 6, 250–264.
Huang,R.-H.; Yang, C.-L. (2008). Overlapping production scheduling planning with multiple objectives – An ant colony approach. International Journal of Production Economics, 115 (1), 163-170.
Hwang, H.-S. (2005). An integrated distribution routing model in multi-supply center system. International Journal of Production Economics, 98 (2), 136-142.
Lee, C.Y.; Chen Z.L. (2001). Machine scheduling with transportation considerations. Journal of Scheduling, 4, 3-24.
Li, C.-L.; Vairaktarakis, G.; Lee, C.-Y. (2005). Machine scheduling with deliveries to multiple customer locations. European Journal of Operational Research, 164, 39-51.
Li, K.; Sivakumar, A.I.; Ganesan, V.K. (2008). Analysis and algorithms for coordinated scheduling of parallel machine manufacturing and 3PL transportation. International Journal of Production Economics, 115 (2), 482-491.
Lin, B.M.T.; Lu, C.Y.; Shyu, S.J.; Tsai, C.Y. (2008). Development of new features of ant colony optimization for flowshop scheduling. International Journal of Production Economics, 112 (2), 742-755.
Park Y.-B. (2001). A hybrid genetic algorithm for the vehicle scheduling problem with due times and time deadlines. International Journal of Production Economics, 73 (2), 175-188.
Potts, C.N. (1980). Analysis of a heuristic for one machine sequencing with release dates and delivery times. Operations Research, 28, 1436-1441.
Pundoor, G.; Chen, Z.L. (2005). Scheduling a production-distribution system to optimize the trade-off between delivery tardiness and distribution cost. Naval Research Logistics, 52, 571-589.
Pundoor, G.; Chen, Z.L. (2009). Joint cyclic production and delivery scheduling in a two-stage supply chain. International Journal of Production Economics, 119 (1), 55-74.
Raa, B.; Aghezzaf, E.-H. (2008). Designing distribution patterns for long-term inventory routing with constant demand rates. International Journal of Production Economics, 112 (1), 255-263.
Sahin, F.; Robinson, E.P.; Gao, L.-L. (2008). Master production scheduling policy and rolling schedules in a two-stage make-to-order supply chain. International Journal of Production Economics, 115 (2), 528-541.
Sarmiento, A.; Nagi M.R. (1999). A review of integrated analysis of production-distribution systems. IIE Transportation, 31, 1061-1074.
Sawik, T. (2009). Coordinated supply chain scheduling. International Journal of Production Economics, 120 (2),

437-451.

Scholz-Reiter, B.; Freitag, M.; de Beer, C.; Jagalski, T. (2005). Modelling Dynamics of Autonomous Logistic Processes: Discrete-event versus Continuous Approaches. Annals of the CIRP, 55 (1), 413-417.

Scholz-Reiter, B.; Frazzon, E. M.; Makuschewitz, T. (2009). Integration von Produktions- und Transportsystemen entlang globaler Supply Chains. Industrie Management, 6, 35-38 (in German).

Scholz-Reiter, B. ; Schwindt, C. ; Makuschewitz, T. ; FRAZZON, E. M. . An Approach for the Integration of Production Scheduling and Inter-facility Transportation within Global Supply Chains. In: POMS Annual Conference 2010, 2010, Vancouver. Proceedings POMS Annual Conference 2010.

Stecke, K. E.; Zhao, X. (2007). Production and Transportation Integration for a Make-to-Order Manufacturing Company with a Commit-to-Delivery Business Mode. Manufacturing & Service Operations Management, 9 (2), 206-224.

Surana, A.; Kumara, S.; Greaves, M.; Raghavan, U.N. (2005). Supply-chain networks: a complex adaptive systems perspective. International Journal of Production Research. 43/20, 4235-4265.

Thomas, D.J.; Griffin, P.M. (1996). Coordinated supply chain management. European Journal of Operational Research, 94, 1-15.

Tuy, H.; Ghannadan, S.; Migdalas, A.; Varbarand, P. (1996). A strongly polynomial algorithm for a concave production-transportation problem with a fixed number of nonlinear variables, Mathematical Programming, 72 (3), 229-258.

Valente, J. M.S.; Alves, R.A.F.S. (2007). Heuristics for the early/tardy scheduling problem with release dates. International Journal of Production Economics, 106 (1), 261-274.

Wang, G.; Cheng, T.C.E. (2000). Parallel machine scheduling with batch delivery costs. International Journal of Production Economics, 68, 177-183.

Wang, X.; Cheng, T.C.E. (2009a). Logistics scheduling to minimize inventory and transport costs. International Journal of Production Economics, 121 (1), 266-273.

Wang, X.; Cheng, T.C.E. (2009b). Heuristics for parallel-machine scheduling with job class setups and delivery to multiple customers. International Journal of Production Economics, 119 (1), 199-206.

Woeginger, G.J. (1998). A polynomial-time approximation scheme for single-machine sequencing with delivery times and sequence-independent batch set-up times. Journal of Scheduling, 1, 79-87.

Enzo Morosini Frazzon (enzo@deps.ufsc.br), Antônio G.N. Novaes (novaes@deps.ufsc.br), Joarez Pintarelli Jr. (joarezpj@gmail.com), Gustavo Stelzner (gustelzner@gmail.com)
Campus Universitário UFSC, Centro Tecnológico, Departamento de Engenharia de Produção (DEPS)
88040-110, Florianópolis, SC, Brazil