Decision alignment within supply chain: from a customer/supplier system towrd a multi-echelon model

Maxime Ogier, Van-Dat Cung, Lucas Moureaux, Julien Boissière

Decision alignment within Supply Chain: from a Customer/Supplier system toward a multi-echelon model

Maxime OGIER, Van-Dat CUNG, Lucas MOUREAUX

Univ. Grenoble Alpes, G-SCOP, F-38000 Grenoble, France
CNRS, G-SCOP, F-38000 Grenoble, France
maxime.ogier@grenoble-inp.fr,
van-dat.cung@grenoble-inp.fr, lu.moureaux@gmail.com

Julien BOISSIERE

LISTIC, Univ. de Savoie
B.P. 80439
74944 Annecy-le-Vieux Cedex, France
julien.boissiere@univ-savoie.fr

ABSTRACT: *This paper presents developments on modeling and simulation of decentralized decision making in supply chains. To simulate supply chain, multi-agent systems appear quite natural. However, the natural autonomy of agents and supply chain actors in their decision making questions the consistency of these decisions within the system. Decentralized decisions impact other actors, sometimes in a strong manner and with a risk of inconsistency. This paper focuses on supply chain planning and the associated decentralized decisions: inconsistency on such plans can lead to infeasibility. Starting from a given peer-to-peer negotiation process and its improved version, the purpose is to work with a serial chain of three actors, thus requiring several peer-to-peer discussions. The sequence and synchronization of these discussions, local decisions, and plan validations is not straight forward and the paper identifies 3 major cases. 2 of these cases and the two versions of the peer-to-peer negotiation process are simulated to understand their behavior through time. Generalization toward a* n*-echelon system is also discussed.*

KEYWORDS: *supply chain, decentralized decision, negotiation process, simulation.*

1 INTRODUCTION

Modeling and simulation of production systems can benefit in a quite important way to organizations that use it. Simulation of production processes, flow models or so are very well known and widespread. Today's challenges drive toward modeling and simulation of the global supply chain. The difficult part that comes with this development is strongly linked to the decentralized decision making feature of supply chains. In classical, operational production systems (shop floor, distribution chain), decisions, especially concerning planning, are centralized, made by a global coordinator. They can also be decentralized, but with a very local vision and very few optimization or anticipation considerations (reactive decisions). As supply chain systems involve several autonomous actors, centralization becomes clearly not relevant, and, the different actors are expected to deploy a given level of planning (anticipation) and optimization. The simulation of such a complex system relies on several aspects to model reality: (i) decentralized optimization for decision making and (ii) global consistency of local decisions. Planning concerns are more than important in supply chains and they must often deal with capacity restriction. Notice that in such an interactive system, capacity limits can occur at a point that cannot be considered in the local optimization process: this is the case when a supplier does not have enough capacity to perform a given delivery plan. This rises the need for decision alignment processes (communication and decision making process between several actors) to produce consistent decisions. After a short literature review, this paper briefly presents a 2-echelon (customer-supplier) negotiation process, together with a local optimization process, concerning production plan. Section 4 presents the 3-echelon case with different alignment approaches. Results and discussion end the paper.

2 LITERATURE REVIEW

Decentralized decision making is a strong element in supply chain modeling, in the sense that it is a fact from real cases, and it is a tough challenge. Modeling, simulation and optimization of supply chains must be done taking that element into account. Classical approaches concerning this subject study coordination of the chain through contracts: quantity discount, buy back, revenue sharing or so forth. For an overview, see Govindan et al. (2013) or Cachon (2003). However these models are usually static (infinite horizon), and do not consider demand dynamics. Defining parameters also often requires information that are not always shared through all actors, which some how relates to a form of centralized approach.

Some dynamic or multi-period approaches can still be found in Dudek and Stadtler (2005), Ebrahim et al. (2009) or Homberger (2010).

Another way of integrating variability and dynamics of supply chain is simulation. In the case of supply chain it requires decision processes. As previously discussed, some of these processes need to be decentralized processes to model the reality of supply chain decision making. Jung et al. (2008) is among the first papers that study decision alignment in such a decentralized context with limited information sharing: a customer and its supplier must align their production and transportation plans, only exchanging these plans. An important aspect concerning decentralized decision making stands in what information is shared during the alignment process, and when, a full information exchange being usually unrealistic. Jung et al. (2008) propose minimal information sharing and Seo (2006) real-time inventory. Taghipour and Frayret (2012, 2013) also propose a negotiation process but require sharing critical information between actors: the supplier need to share its "marginal" profit to justify some decisions. The relevance of such alignment processes is strongly related to simulation for two reasons: (1) simulation can give a good insight of the performance of the process through time, its reactivity or robustness to changing conditions such as end customers' demand and (2) these processes represent also a necessary path toward a global simulation of the supply chain.

3 THE PEER TO PEER NEGOTIATION PROCESS

3.1 The system and the local optimization process

The supply chain that is concerned in this section consists in a supplier (manufacturer) and a customer (distributor) which sells product on the final market. The objective is to model and simulate the system in its decentralized version: each actor builds its own production, transportation and storage plan and a negotiation must be processed to reach a decision that is consistent with all constraints. The following elements describe the system:

- The problem is single-product and multi-period, and works on a rolling horizon basis. Notice than apart from computational problems, the case can easily be extended to multi-product as far as the negotiations for each product are independent.
- The local objective of each actor is to minimize its cost, solving a classical lot-sizing problem without fixed cost, over the rolling horizon.
- A end-horizon inventory is set up to guarantee service continuity. Setting its level is beyond the scope of this paper.
- Costs relate to production, storage at both locations, transportation and shortage penalties (lost sales). These costs are only linear costs. Shortage penalties only occur at the end-customer sales point. This cost is set to a rather high value compared to other costs.
- Constraints relate to production capacities at the manufacturer, transportation capacities between actors, storage at both locations. Constraints are kept consistent with the end-customer demand: the total capacity exceeds the total demand through all periods.
- End customer demand is stochastic in the simulation but considered deterministic in the optimization process (local optimization and negotiation).

Decisions relate to a production plan over several periods for the supplier, and transportation plan for the distributor. The optimization is decentralized: each actor solves it own Integer Linear Program. The negotiation process describes 3 basic elements: (1) what information is exchange, (2) how it is integrated in local optimization, and (3) the sequence of the process.

3.2 The negotiation process

The negotiation process is declined from the one proposed by Jung et al. (2008). The initial process works the following way, for each horizon:

1. The distributor optimizes its transportation and storage plan according to its customer demand and local constraints, and sends it to its supplier.
2. Given this plan as a constraint, the manufacturer optimizes its own production plan, considering an incentive "shortage penalty" L, to satisfy the distributor. The manufacturer can propose a new plan as far as quantities for any product in any period are less than the one proposed by the distributor. The difference is subject to the shortage penalty.
3. The distributor receives this production/transportation plan. It can again propose a new one, based on a local optimization, but with the same constraint: a quantity for a given product in a given period cannot be increased.
4. The process starts back to step 2 and ends when plans do not change during an exchange. At that time, because plans are aligned, the supplier do not face any shortage penalty L.

Details concerning this process can be found in Jung et al. (2008).

Ogier et al. (2012b) proposed an improvement to this process, arguing that this initial version can lead to very poor performance in some cases. The non-increasing constraint on every period is very strict and often leads to a poor end-customer service, generating high shortage penalties. The improvement from Ogier et al. (2012b) relies on the possibility for both actors to increase the quantities for every periods as far as the following two natural conditions stand:

- The overall quantity through the entire planning horizon do not increase: the global volume is not increasing.
- The increase during a period is used to balance a decrease in a future period, not in a previous one: anticipation is allowed, not lateness.

These two conditions are very natural as they allow anticipated production or delivery while keeping the global volume bounded to the actual need of the distributor: early production is relevant if capacity cannot be adapted to demand fluctuations. This new process is more relevant to reality and provide more interesting results. The reader can refer to Ogier et al. (2012b) for a more detailed and complete view of it. The two preceding processes are used and compared in this paper, but details are not of great importance as the following developments are not linked to the peer-to-peer negotiation process itself. Notice anyway that the following developments and results only consider a single-item system. The extension of the principles to multi-product is easily manageable in a modeling point of view but computing and interpretation problems make it less relevant to a first extend. As already mentioned, this is true as far as each product is negotiated in independently.

The former negotiation is a 2-echelon, peer-to-peer one. An extension to multi-supplier / single-customer or single-supplier / multi-customer can be found in Ogier et al. (2012a) and is not discussed here. The purpose of this paper, is to present the 3-echelon case, and more generally the n-echelon case.

4 THE 3-ECHELON ALIGNMENT PROCESS

In order to simulate supply chains, it is necessary to handle multi-echelon systems, and thus to be able to drive alignment in such a context. However, if this is quite an easy task when decision is centralized (apart from computational complexity considerations), it is not the case in a decentralized context. Indeed, constraints from other actors of the chain (upward or downward) can result in unfeasible plans. Figure 1 represents a simple view of the system: a supplier, a manufacturer and a distributor. Compared to the 2-echelon case however, the middleman needs to perform two alignment processes: one with its customer, and one with its supplier. The sequence, timing or synchronization of these processes is not straight forward and different assumptions or cases can be studied. This paper explores 3 cases that grab the most commonly encountered situations. Notice that there is no parallelism in internal decision making, and that the processes are assumed to end-up in the same period they started. This means that nothing has changed in the actors' environment.

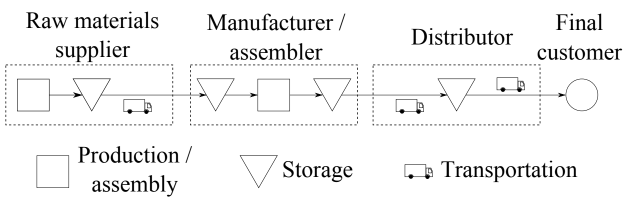

Figure 1: The 3-echelon supply chain.

This section only presents the three cases. The tests and results are described in section 5.

4.1 Overall alignment

The first alignment process considered here is "Overall Alignment". This process (figure 2) works the following way:

1. The distributor sends its optimal transportation plan to the manufacturer.
2. The manufacturer and its supplier perform a full peer-to-peer negotiation on their common plan.
3. The manufacturer sends the result of the process to the distributor.
4. If this plan is not the one initially required by the distributor, it performs a new local optimization based on the new plan, and the process starts back to step 1, otherwise it ends.

In this case, described in figure 2, the manufacturer have to deal with both sides and for each transportation planning submitted by the distributor, supplier and manufacturer perform n iterations to find a close plan and submit it to the distributor. To summarize, the three actors are tied and need to find transportation plans that everyone agree with. This case is a kind of ideal case in the sense that it ends up with a commonly agreed plan: the plan is feasible. And because the peer-to-peer negotiation converges, this process converges as well. This approach is consistent in the case of simple supply chains, but not really realistic for very complex ones as the number of iterations

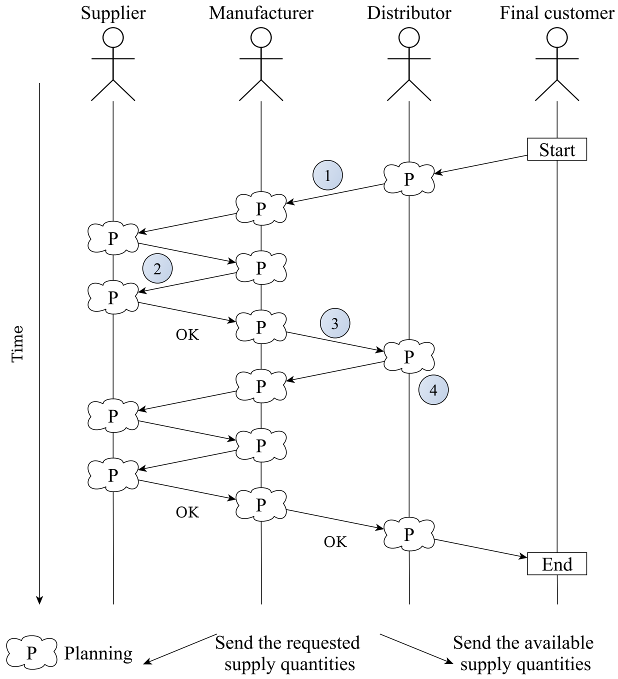

Figure 2: The overall alignment process.

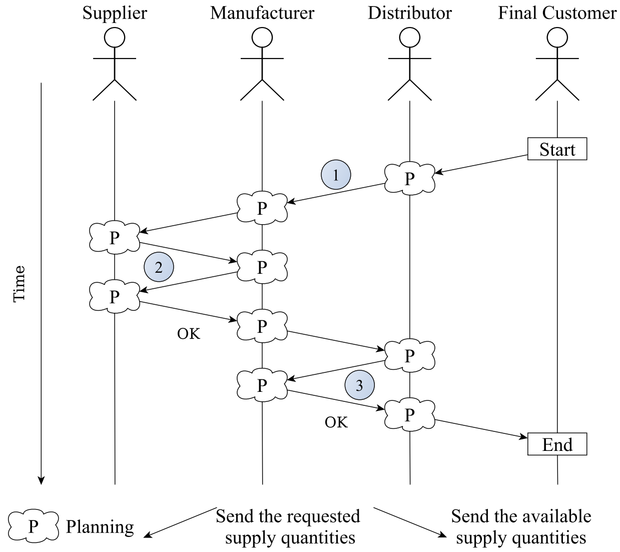

Figure 3: Supplier priority alignment process.

needed to converge and therefore, the alignment time required, become far too high. This can be handled to a reasonable extend but it quickly questions the single-period duration of the alignment process.

4.2 Supplier priority alignment

This supplier priority alignment process from figure 3 works the following way:

1. The distributor sends its optimal transportation plan to the manufacturer.
2. The manufacturer and its supplier perform a full peer-to-peer negotiation on their common plans, which become definitive at this step.
3. Then, the manufacturer and the distributor terminate the peer-to-peer process initiated in step 1. The manufacturer can not change its supply plan.

In this case, the supplier/manufacturer is independent to the rest of the process as it is performed as a closed loop (no external disruption). Notice however that the alignment process start once again with a demand plan from the distributor, which somehow drives the supplier/manufacturer negotiation. This case's performance is expected to be less interesting for two reasons:

- The manufacturer can face oversized inventory if its customer changes its mind after the upward negotiation, generating over costs and possibility of storage overload. However, feasibility of the plans is still reached if this storage overload can be handled (e.g. using additional storage space or product destruction). Notice that any of these example should be modeled in the local optimization process.
- In the case of an increase in its customer's demand, the manufacturer can face a raw material stock out: this does not question feasibility but performance level. To protect from such a case, the manufacturer could hold a safety stock.

In terms of negotiation time and iterations, it should be noticed two main things: (i) the total number of plans exchanges is reduced, (ii) for the distributor, the delay between its first plan and a first answer can be long.

4.3 Customer priority alignment

This customer priority alignment process from figure 4 works the following way:

1. The distributor and the manufacturer perform a full peer-to-peer negotiation. This gives a definitive transportation plan between the manufacturer and distributor.
2. Based on the results of step 1, the manufacturer performs a full process with its supplier. The end of this process ends the full process.

The major advantages of this alignment process are the following: (i) low number of iterations and (ii) limited time for each process. For this reason it is a

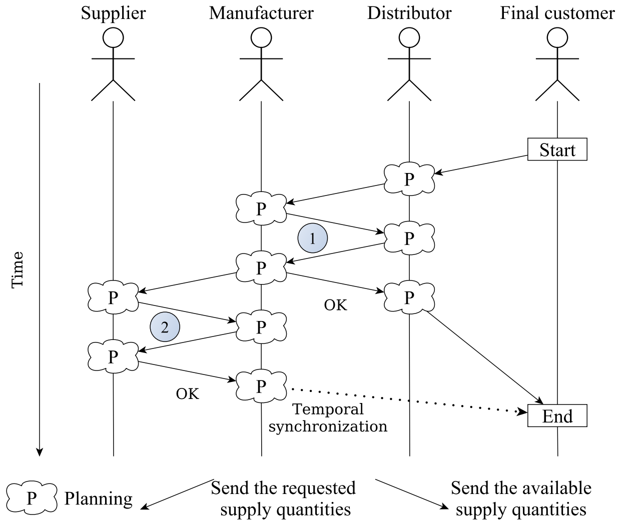

Figure 4: Customer priority alignment process.

quite realistic one. Moreover, notice that it is just a sequence of two independent peer-to-peer processes: once started, a negotiation process is not interrupted.

However, this process faces a major problem which is that it can be hard to reach a feasible plan, as the supplier capacity is not considered in step 1. Several ways can be considered to tackle this problem: using beliefs on the supplier's capacity over the horizon, some kind of allotted capacity through contracting, or introducing a back-up supplier. These solutions are not discussed in this paper but are interesting prospects for this research, especially in a multi-agent environment. Notice also that this case has not been simulated and is thus not analyzed in the paper because of this potential absence of convergence.

5 RESULTS AND DISCUSSION

Simulation of the decentralized planning process in a 3-echelon supply chain has been implemented for the overall alignment process and the supplier priority alignment process. The implementation is based on a multi-agent platform developed in Java to simulate the planning process (decentralization of the decision, use of negotiation processes, rolling horizon). The local planning are optimization problems implemented with the interface Concert Technology and solved with CPLEX 12.3.

The experimental results of this section validate the use of the peer to peer negotiations exposed in section 3 within the 3-echelon model. Moreover, based on an instance structure with fluctuating demands and capacities the results allow a discussion on the following elements:

- the influence of the quantity of available information (rolling horizon length) on the global performance of the supply chain;
- the impact of the peer-to-peer negotiation process on the supply chain performance;
- the impact of the alignment processes (overall vs. supplier priority) on the supply chain performance;
- the distribution of costs between the supply chain actors.

5.1 Instance structure

The studied instance aims at representing a planning problem in a 3-echelon supply chain with fluctuating demands and capacity issues. The plan is made on multi-period horizon, with one strategic product. Hence the final customer demand for each period t is considered very fluctuating: $D_t = U(500; 1500)$ where $U(a; b)$ is the uniform distribution between a and b. Table 1 presents the detailed values for capacities and costs. Production capacities are fluctuating, with an average overcapacity, decreasing along the supply chain: 10% overcapacity for the supplier and 5% for the manufacturer. Transportation capacities are fluctuating as well, with an overcapacity of 20%. Transportation from the distributor to the final customer is set to the maximal demand, hence the distributor is always able to deliver the customer. Since production and transportation capacities are fluctuating, actors can use storage. For the supplier and the manufacturer, capacity is set at 40% of average demand since this is not their core business, and storage capacity is set to the average demand for the distributor. Costs are considered constant over time since the instance focuses on capacities issues. Note that unit storage costs are increasing along the supply chain since the value of the product increases after the production process performed by the manufacturer. Moreover, unit shortage penalty costs are defined in the peer-to-peer negotiations when a supplier cannot satisfy its customer's demand. Notice that this penalty is never paid if alignment is reached.

Since the planning is done on a rolling horizon basis, a final inventory level is expected at each storage location in order to achieve continuity of the service. This level is set to 40% of the storage capacity. Instead of warm-up periods for the simulation, an initial inventory level at 40% of the storage capacity is considered, for every storage point. The improved peer-to-peer negotiation process proposed in Ogier et al. (2012b) needs penalty costs associated to increased proposals. Let us consider the rolling horizon is on T periods. At period t, the unit penalty costs is $500 + 100 \cdot (T - t)$ if the increase is proposed to the customer and $500+100 \cdot t$ if the increase is proposed to the supplier. These values follows the rules proposed in Ogier et al. (2012b).

Demand		$U(500;1500)$
Production capacities	Supplier	$U(850;1350)$
	Manufacturer	$U(800;1300)$
Transportation capacities	From Supplier	$U(1000;1400)$
	From Manufacturer	$U(1000;1400)$
	From Distributor	1500
Storage capacities	Supplier	400
	Manufacturer (up)	400
	Manufacturer (down)	400
	Distributor	1000
Production costs (unit)	Supplier	100
	Manufacturer	100
Transportation costs (unit)	From Supplier	25
	From Manufacturer	25
	From Distributor	25
Storage costs (unit)	Supplier	20
	Manufacturer (up)	20
	Manufacturer (down)	40
	Distributor	40
Shortage penalty costs (unit)	Supplier	10000
	Manufacturer	10000
	Distributor	10000

Table 1: Instance description.

For each instance, 20 replications of the uniform distribution are generated. All the results presented are the average results based on these 20 replications. The simulation runs on a 50 periods horizon, with a rolling planning horizon from 2 to 15 periods.

5.2 Results and analysis

The following results are presented for four cases in the 3-echelon supply chain:

- An ideal case (named *Ideal case*) in which the decisions are centralized using one decision-maker for the whole supply chain, and all the data are available at the beginning (rolling horizon do not applied). This unrealistic but ideal case gives a lower bound for the optimal performance of the whole supply chain.
- The use of the basic peer-to-peer negotiation proposed by Jung et al. (2008) (named *Basic P2P*). In this case, the overall and the supplier priority alignment processes give the same results so they are not distinguished. Indeed, within this negotiation and the considered planning problem, the customer has no interest to decrease the proposal of its supplier.
- The use of the improved peer-to-peer negotiation proposed by Ogier et al. (2012b) within the overall alignment process for the 3-echelon supply chain (named *Improved P2P / Overall alignment*).
- The use of the improved peer-to-peer negotiation proposed by Ogier et al. (2012b) within the supplier priority alignment process for the 3-echelon supply chain (named *Improved P2P / Supplier priority alignment*).

In order to evaluate the global performance of the supply chain, figure 5 presents the average final customer's lost sales for the whole simulation. In the *ideal case*, these lost sales are negligible (about 0%). With the *basic P2P* case, the performance is very far from the *ideal case*, even when actors have better knowledge about the future (15 periods rolling horizon). This is due to the combination of (i) the distributor has a large overcapacity (+20%) which favor a just-in-time plan, and (ii) the manufacturer only has a 5% overcapacity with low storage capacities and needs to coordinate with its supplier which make difficult the satisfaction of all the distributor's demands. Rather good results for a two periods planning horizon are due to the final inventory level which enables more anticipation for the actors with this low vision of future demand. The use of the improved peer-to-peer negotiation implies a decrease of the lost sales when more information are available (longer rolling horizon length). Hence this peer-to-peer negotiation takes better advantage of the available information. The ideal case is not reached however since there are still coordination issues across the three echelon of the supply chain. Besides, the use of overall or supplier priority alignment process very slightly affects the performance: a better performance is obtained within the supplier priority alignment process for long horizons.

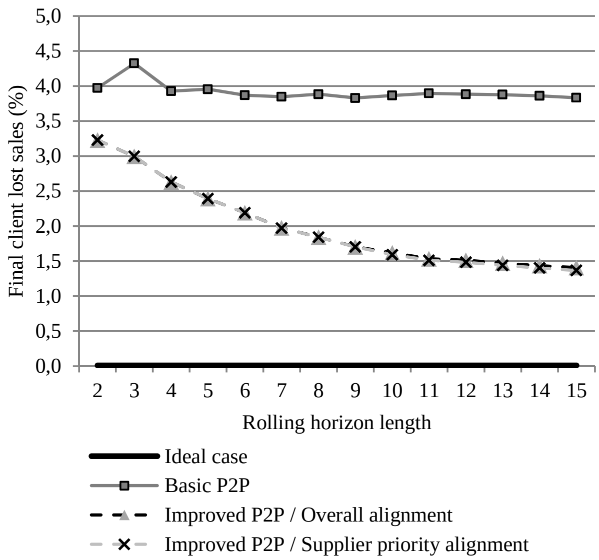

Figure 5: Lost sales for the final customer.

The supply chain performance can also be evaluated through the individual performance of the three actors. Hence, figures 6, 7 and 8 present the total cost for each actor. For the distributor, results are consistent with the global performance of the supply chain since it supports the lost sales penalty of the final customer, which represent the largest part of all costs. When the actors use the *basic P2P* negotiation, the cost for the manufacturer and the supplier are lower than in the *ideal case* since there are high lost sales hence less production activity. When the *Improved P2P* negotiation is used, the costs for the manufacturer and the supplier are higher, especially when planning with large rolling horizon, because of the use of storage in order to achieve the continuity of service. An interesting result is the better performance in the case of *supplier priority alignment* process. In this case the manufacturer does not reconsider the decisions taken with its supplier during the negotiation with its customer leading to a higher inventory hence a greater ability to satisfy the distributor's demand in future periods. For the supplier, this leads to an increased production level (even if some over storage occurs: products are thrown out by the manufacturer). This results in a higher cost as depicted in figure 8.

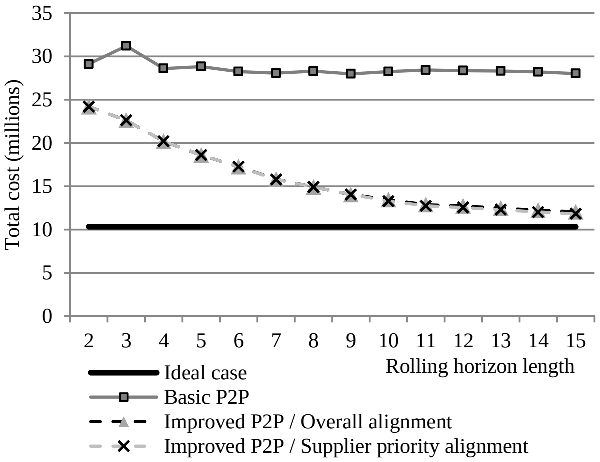

Figure 6: Total cost for the distributor.

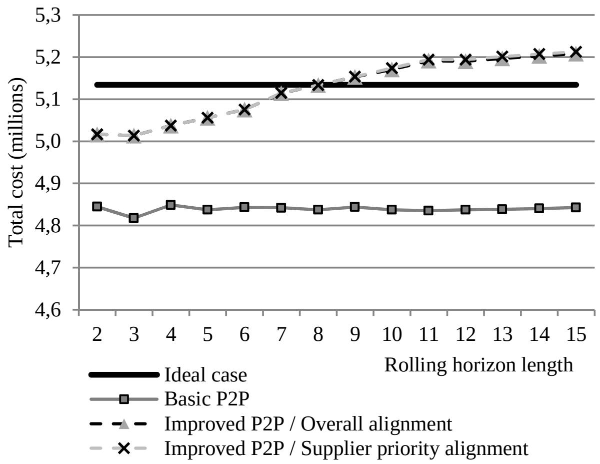

Figure 7: Total cost for the manufacturer.

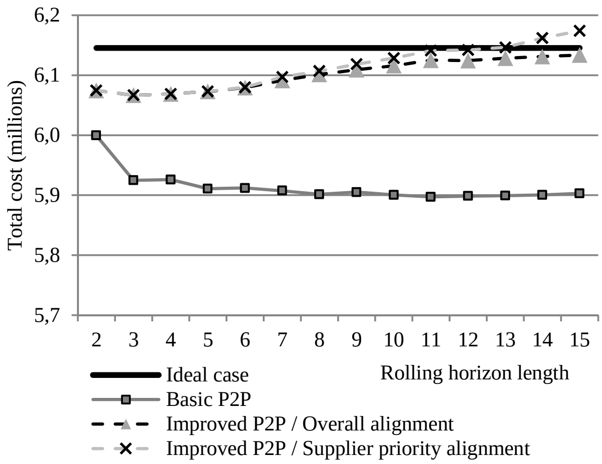

Figure 8: Total cost for the supplier.

These results also show the proposed alignment process in a 3-echelon supply chain works well (overall and supplier priority alignment processes). Moreover, they permit to validate the good performance of the improved peer-to-peer negotiation with respect to the basic one. An unexpected result is the better performance with the use of supplier priority alignment process: less negotiation can improve the global performance of the system.

Thus the proposed 3-echelon model seems to be relevant in order to simulate a decentralized decision making in 3-echelon supply chain. Tests have been conducted with two peer-to-peer negotiation processes, but the proposed alignment processes are generic so other negotiation processes can be used. These preliminary results can be enhanced by testing the customer priority alignment process, which necessitate to work on the guarantee of the convergence to a feasible solution. Moreover, the proposed alignment processes on 3-echelon can be directly extended to a n-echelon supply chain. Increasing the number of echelon highlight two major concerns: (i) how is the global performance affected when adding an echelon, and (ii) how to balance the performance of the system with the performance of the negotiations (the assumption of no changes during the negotiation stays only if the number of negotiations is reasonable).

6 CONCLUSION

This work gives some insights about how to model and simulate supply chain decentralized decision making by proposing different decision alignment processes required to guarantee plans consistency. The proposed processes consist in frameworks where local optimization models and peer-to-peer negotiation processes can be plugged-in. Preliminary results show how these frameworks and the peer-to-peer negotiations can be evaluated in the context of a planing problem in a 3-echelon supply chain with two different negotiation processes. This work is exposed in a 3-echelon context but it can directly be extended to n echelons to simulate a complete serial supply chain.

Many prospects can be derived from this work. A first one is to study the customer priority convergence to be able to test it and compare it with the other alignment processes. Moreover, the vertical complexity of the supply chain should be combined with an horizontal one: multi-customer and/or multi-supplier cases. This can be done using results from Ogier et al. (2013).

ACKNOWLEDGMENTS

Funding for this research was provided by a grant from la Région Rhône-Alpes.

REFERENCES

Cachon, G. P. (2003). Supply chain coordination with contracts, *in* S. Graves and A. de Kok (eds), *Supply Chain Management: Design, Coordination and Operation*, Vol. 11 of *Handbooks in Operations Research and Management Science*, Elsevier, pp. 227–339.

Dudek, G. and Stadtler, H. (2005). Negotiation-based collaborative planning between supply chains partners, *European Journal of Operational Research* **163**(3): 668–687.

Ebrahim, R. M., Razmi, J. and Haleh, H. (2009). Scatter search algorithm for supplier selection and order lot sizing under multiple price discount environment, *Advances in Engineering Software* **40**(9): 766–776.

Govindan, K., Popiuc, M. N. and Diabat, A. (2013). Overview of coordination contracts within forward and reverse supply chains, *Journal of Cleaner Production* **47**(0): 319 – 334.

Homberger, J. (2010). Decentralized multi-level uncapacitated lot-sizing by automated negotiation, *4OR* **8**: 155–180.

Jung, H., Chen, F. F. and Jeong, B. (2008). Decentralized supply chain planning framework for third party logistics partnership, *Computers & Industrial Engineering* **55**(2): 348–364.

Ogier, M., Cung, V.-D. and Boissière, J. (2012a). Development of a sustainable supply chain planning tool coupling simulation and optimization techniques, *Proceedings of the 1st International Workshop on Green Supply Chain (4 pages), Arras, France.*

Ogier, M., Cung, V.-D. and Boissière, J. (2012b). An improved planning coordination in a decentralized 2-echelon supply chain, *Proceedings of the 4th International Conference on Information Systems, Logistics and Supply Chain (10 pages), Quebec, Canada.*

Ogier, M., Cung, V.-D., Boissière, J. and Chung, S. (2013). Decentralised planning coordination with quantity discount contract in a divergent supply chain, *International Journal of Production Research* **51**(9): 2776–2789.

Seo, Y. (2006). Controlling general multi-echelon distribution supply chains with improved reorder decision policy utilizing real-time shared stock information, *Computers & Industrial Engineering* **51**(2): 229 – 246.

Taghipour, A. and Frayret, J.-M. (2012). Mutual adjustment search with incentive for supply chain planning coordination, *International Journal of Computer Integrated Manufacturing* **25**(10): 946–962.

Taghipour, A. and Frayret, J.-M. (2013). Dynamic mutual adjustment search for supply chain operations planning co-ordination, *International Journal of Production Research* **51**(9): 2715–2739.