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Procedia Engineering 132 (2015) 942 – 949

Procedia Engineering

www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2015

Decentralized Manufacturing Supply Chains Coordination under Uncertain Competitiveness

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Abstract

The coordination of decentralized multi-product manufacturing SCs is achieved through negotiations based on expected win-win principles in an uncertain competitive environment. Based on non-symmetrical roles of the different actors, the client (as leader) is supposed to propose coordination contracts according to its best expected conditions, taking into account the uncertain reaction of the provider (follower). This uncertain reaction is modeled as a probability of acceptance, computed according to the overall scenario conditions, which include the presence of 3rd parties. Different negotiation scenarios are analyzed considering cooperative and non-cooperative cases. The resulting MINLP tactical models are illustrated using a case study with different providers (follower SC) around a client (leader SC) interacting in a global decentralized scenario. The negotiations based on non-cooperative cases proves to identify the situation with higher independent profit expectations. Moreover, the proposed approach shows the importance of considering the uncertainty associated with the response of the follower to the leader's decisions, resulting from a wider knowledge of its options.

Peer-review under responsibility of the Scientific Committee of MESIC 2015

Keywords: Manufacturing Planning, Decentralized Supply Chains, Coordination, Negotiation, Uncertainty.

1. Introduction

The competitiveness between the manufacturing industries shifts the focusing of decision-makers towards the coordination of their Supply Chains (SCs), based on individual and global objectives. Many works have been carried

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Peer-review under responsibility of the Scientific Committee of MESIC 2015
doi:10.1016/j.proeng.2015.12.581

out on the internal coordination between the different echelons of a SC through the supply/demand flow coherence at the tactical level [1, 2]. But these works focus on the global objective of the system from a centralized perspective, disregarding the individual goals, which are crucial when dealing with complex superstructures of decentralized manufacturing SCs, especially when different stakeholders with conflicting objectives are involved; each stakeholder seeking to optimize its own benefits no matter how the other participating stakeholders' uncertain reactions will be.

Many works have been carried out to solve these complexities such as [3], who propose a "revenue sharing" negotiation approach for one manufacturer-different competing retailers SC. However, in their work, the manufacturer provides the initial production plan based on its own uncertain conditions, disregarding the uncertain behavior of the retailers SCs, which may lead to SC disruptions. Another negotiation method has been developed by [4] for a manufacturer-retailer SC, based on bi-directional option contracts (call option/put option); for the call option, the manufacturer can buy a specific amount of products at a specific price, while for the put option, the retailer must pay an allowance for cancelling or returning an order. Multi-agent systems also have been proposed as a negotiation strategy, such as the work of [5], who develop a multi-agent tactical model for the optimization of a Brazilian oil SC in order to identify the oil products transport plan. However, the multi-agent-based negotiations are built on cooperative SCs, in which all participating agents cooperate with one common objective function, disregarding the individual objectives and their uncertain nature, which may affect the performance of the whole system. Game Theory also has been used for the optimization of decentralized SCs such as [6], who propose a game theory strategic-tactical model; they solve the competitiveness among the suppliers/retailers based on cooperative games through Nash Equilibrium, while the interactions between the manufacturer and the suppliers/retailers are modeled as non-cooperative Stackelberg games. However, in their cooperative games, the competitive suppliers have to sell to the manufacturer (client), giving the client a dominant leadership, disregarding the uncertain reaction of the follower SCs (suppliers/retailers), which may lead to disruptions that may affect the global SC equilibrium.

Notwithstanding, current negotiation methods for decentralized manufacturing SCs coordination allow to provide individual decisions based on static cases, without knowing the whole SC picture and how the other partners may react, leading to incomplete decision-making, particularly, when negotiation partners are subjected to risk due to the uncertain nature of their 3rd parties, where the novelty of this work lies. Accordingly, this work proposes a scenario-based negotiation approach as a decision-support tool to set the best conditions for eventual coordination contract between manufacturing SCs stockholders with conflicting objectives within a multi-site multi-product decentralized SC. The proposed approach extends the limits of the SC of interest to consider both clients and providers, with their respective manufacturing SCs, as part of the global system, in order to improve the decentralized SCs tactical decision-making through cooperative and no-cooperative negotiations built on expected win-to-win principles.

Nomenclature

Indexes

r	resource (raw material, internal/final product, energy, …)
SC	supply chain
Sc'	negotiation partners SCs
t	time period
Sets	
L	leader
F	follower
SC	supply chain
S	RM supplier
PL	production plant
W	warehouse/distribution center
M	external markets (final customer)
R	resources (RM, products, man power, energy, etc.)
r'	negotiation resource
T	time periods

Parameters	
$rp_{r,sc,m}$	unit cost value of resource r to the final market m
Variables	
$RS_{r',sc',t}$	negotiation resources r' between the negotiating partners sc' at time t
$RS_{r,sc,m,t}$	resources r flows from sc to final markets m at time t
$RS_{r',w',sc',t}$	resources r' flows from warehouses w to internal markets/leader sc' at time t
$PROF_{sc}$	aggregated profit of supply chain sc
$Tprofit$	aggregated profit of the whole system
$SALE_{sc}$	economic incomes (sales value) of supply chain sc
$COST_{sc}$	cost of supply chain sc
CRM_{sc}	RM cost
CPR_{sc}	production cost
CST_{sc}	storage cost
CTR_{sc}	transport cost
$p_{r',sc'}$	unit cost of the negotiation resource r' for sc'
$LRS_{r',sc',t}$	Negotiation resource r' amounts resulting from optimizing sc' (leader)
$ExPROF_{sc'}$	Expected sc' (leader) aggregated profit
$prob_{sc'}$	probability of acceptance

2. Methodology

Within a decentralized manufacturing SC, the negotiating partners are the client and the provider, and the negotiation item is the internal product flows (physical/economic) between their manufacturing SCs. The reaction function is identified to be the quantity and the price of the item subject to negotiation at each time edge along a discrete planning horizon. Assuming non-symmetrical roles, and under the leading role of the client, the leader designs a set of coordination contracts based on its best conditions, taking into account the risk associated with the follower SC external conditions, represented by the probability of acceptance. To respond flexibly, the follower analyzes the leader contract offers based on its probability curves. The negotiation methodology is divided into two main parts: 1) analyzing the negotiation scenarios, and 2) preparing the final coordination agreement. As first step, the negotiating partners optimize their individual benefits independently (standalone case), without considering the negotiation item, to be used as benchmarks for all negotiation methods.

2.1. Negotiation scenarios

i) Cooperative Negotiation Scenario (CNS): the negotiating partners form a coalition towards maximizing the global SC profit.
ii) Non-Cooperative Negotiation Scenario (nCNS): the negotiating partners, independently, optimize their SCs benefits, taking into consideration the negotiation item along the planning time horizon.

2.2. Preparing the final coordination agreement

From the leader's side: the benefits of any reduction in the uncertainty associated with the signature of the coordination contract are considered, which is modeled as the probability of acceptance of this agreement by the follower SC. To calculate the probability of acceptance, a set of uncertain scenarios (follower SC) is generated using Monte-Carlo method. The leader then uses these values for calculating the expected benefits. Therefore, the proposed contract by the leader will be the one that leads to its highest expected benefit

From the follower's side: based on the proposed leader contract, the follower assesses the risk associated with accepting or rejecting this offer based on its SC expected benefits probability curves. If the expected profits resulting from accepting the offer have higher probabilities, then it would be preferable for the follower to accept the offer.

3. Mathematical model

3.1. The tactical base model

A tactical generic model has been developed and spread or modified according with each scenario. To represent the negotiation strategy, a set of supply chains (sc1, sc2…, SC) is considered with their subsets linking each SC to its corresponding negotiation partner (follower F or leader L). Moreover, the model includes a set of resources r, external suppliers s, production plants pl, warehouses w, and external markets m. The total sales (Eq. 1) include the sales to the leader (L) plus the sales to the external markets (M); where $p_{r',sc'}$ and $rp_{r,m,t}$ are the internal product and the final product prices, respectively.

$$SALE_{sc} = \sum_{r\in R}\sum_{m\in M}\sum_{t\in T} rp_{r,sc,m} \cdot RS_{r,sc,m,t} + \sum_{r'\in R}\sum_{t\in T} p_{r',sc'\in F} \cdot RS_{r',sc'\in F,t} \qquad \forall sc \in SC \qquad (1)$$

The SC Cost along the discrete planning time horizon T is the summation of the RM purchase, production, storage, transport, and the negotiation item total costs, respectively (Eq. 2). Here can be understood the conflictive objectives between the leader and the follower, as the value of the negotiation item is considered as sale when the SC belongs to the follower (Eq. 1) and as cost when the SC belongs to the leader (Eq. 2).

$$COST_{sc} = CRM_{sc} + CPR_{sc} + CST_{sc} + CTR_{sc} + \sum_{t\in T}\sum_{r'\in R} p_{r',sc'\in L} \cdot RS_{r',sc'\in L,t} \qquad \forall sc \in SC \qquad (2)$$

The objective function corresponds to the maximization of the SC profit (Eq. 3).

$$PROF_{sc} = SALE_{sc} - COST_{sc} \qquad \forall sc \in SC \qquad (3)$$

3.2. Application of negotiation scenarios

i) Cooperative negotiation scenario (CNS): the global SC profit (Tprofit) (Eq. 4).

$$Tprofit = \sum_{sc\in SC} PROF_{sc} \qquad (4)$$

ii) Non-cooperative negotiation scenario (nCNS): the negotiation resource quantity $RS_{r',sc',t}$ in the base model will be substituted by a constant value $LRS_{r',sc',t}$ resulted from optimizing the leader SC benefits.

<u>Uncertainty reduction cost</u>

The uncertainty reduction cost can be represented within the expected leader SC profit ($ExPROF_{sc'}$) as an “abridged” uncertainty risk (Eq. 5), which will be represented by the probability of acceptance.

$$ExPROF_{sc'\in L} = PROF_{sc'\in L} - uncertainty\ risk_{sc'\in F} \qquad \forall sc' \in SC \qquad (5)$$

4. Case study: results and discussion

The developed MINLP tactical models are implemented and solved for a real data case study modified from Hjaila et al. (2014) (Fig.1). The negotiating partners are the polystyrene manufacturing SC stakeholder (as leader) and the energy generation SC stakeholder (as follower). The internal energy provided/demanded will be the item to be negotiated (amounts and price). The internal energy price offered by the leader varies between 0.14€/kWh to 0.22€/kWh.

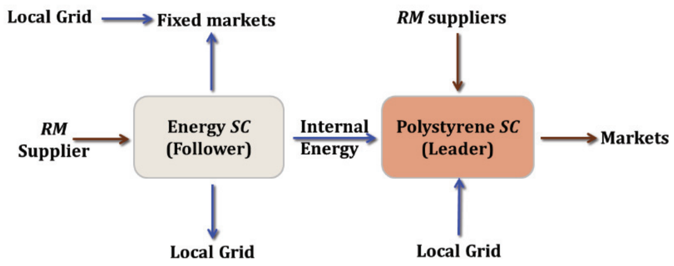

Fig. 1. Decentralized SC network

The case study is modelled using the General Algebraic Modeling System GAMS 24.2.3 on a Windows 7 computer with Intel® Core™ i7-2600 CPU 3.40GHz processor with 16.0 GB of RAM, and the resulting tactical MINLP models have been solved for 6 time periods of 1000 working hours each, using Global mixed-integer quadratic optimizer "GloMIQO [7]". The tactical decisions achieved are the expected RM acquisition, internal product and price, production, inventory, and distribution levels.

4.1. Results- negotiation scenarios

Considering a nominal situation based on fixed market energy prices (0.20 €/kWh for energy selling to external markets, 0.19-0.21 €/kWh for energy selling to the local Grid, 0.22 €/kWh for energy buying from the local Grid to the external energy markets, and 0.20-0.22 €/kWh for energy buying from the local Grid to the leader SC.), the total and individual SCs profits resulting from the different leader contract offers are obtained (Fig. 2 and 3) and compared with the standalone case (SS), so the negotiation only has sense when the profits exceed the standalone benefit. From the leader side (Fig. 2), it seems that the nCNS leads to better solutions than the CNS at all negotiation prices offers, although the CNS leads to higher overall profits.

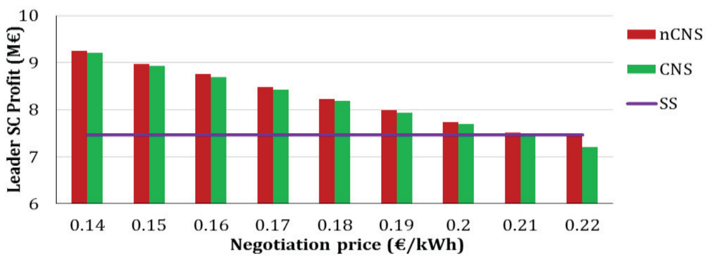

Fig. 2. Leader SC nominal profit vs negotiation price

From the follower side, it is noticed that for negotiation prices above 0.18 €/kWh, the CNS would lead to better profits, if the risks associated with its SC uncertain external conditions are not considered.

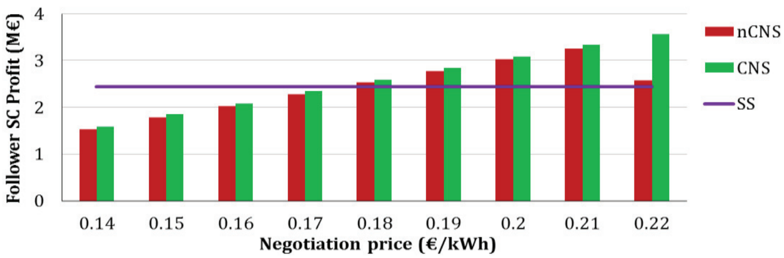

Fig. 3. Follower SC nominal profit vs negotiation price

Since the nCNS proves to be the most adequate negotiation approach from the leader side, it will be considered for preparing the coordination contract agreement.

4.2. Results- coordination contract agreement

So, in order to drive the negotiations towards expected win-win outcomes, the uncertain reaction of the follower resulted from its uncertain external conditions is represented as probability of acceptance in the objective function of the leader SC model. From the leader side: Fig. 4 illustrates the leader expected profits vs. the follower's probability of acceptance (eqs. 5 and 6), compared with the leader nominal profits (at the fixed markets energy prices). It is expected that the probability of acceptance increases as the contract price increases; but at contract price 0.22 €/kWh, the leader decides to buy higher amounts of energy from the local Grid, resulting in a sudden probability of acceptance reduction. It is to be noticed that the highest expected leader SC profit is at contract price 0.15 €/kWh; 12 % less than its nominal profit at the same price. The total energy amount needed for the Polystyrene manufacturing during the established long term planning horizon is 24.71GWh; 36% of this amount is expected to be provided by the energy generation SC (8.94 GWh), while the rest is to be covered by the local Grid. It is worth mentioning that before considering the uncertain reaction of the follower, the contract price 0.14€/kWh was the best option for the leader, but after considering the uncertain reaction of the follower, the leader offers higher price (0.15€/kWh).

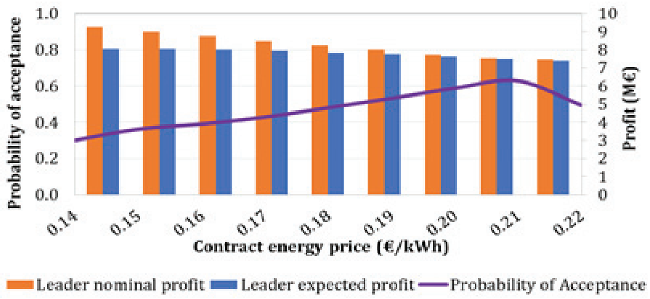

Fig. 4. Leader nominal and expected Profits vs. Probability of acceptance

From the follower side: the follower now assesses this final offer in order to respond (accept or reject), based on its SC expected benefits probabilities (Fig. 5), as follows:

- To accept: expected energy SC profit (nCNS) = 2.46 M€.
- To reject: the follower SC Profit at the nominal expected SS are obtained based on the uncertain scenarios, and the probability curves are obtained for both accepting and rejecting (Fig.5). However, the expected profit resulting from accepting the contract seems to have higher probabilities (Fig. 5), in which the follower should accept in order to avoid any disruptions resulting from the uncertain behavior of its 3rd party.

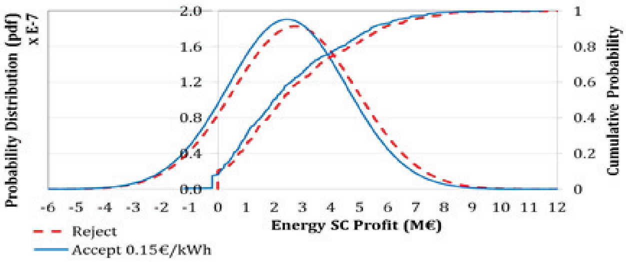

Fig. 5. Probability distribution and cumulative probability curves

4.3. Results- tactical decisions

Fig. 6 summarizes the contract energy demands according with the negotiation outcome. It is noticed that the total energy demanded for the leader manufacturing processes is the same (24.71 GWh) for the nCNS and the SS, as the option is to fulfill the polystyrene final markets demands. However, the energy demanded for the leader manufacturing processes (24.68 GWh) is 0.1% less in the case of CNS, which means quantitatively a difference of 21.86 MWh. In fact, this means that the decision to be taken is to not fulfill the final polystyrene markets demands, since it only represents 0.1 % reduction in the economic sales (17.11 k€)(Fig. 7).

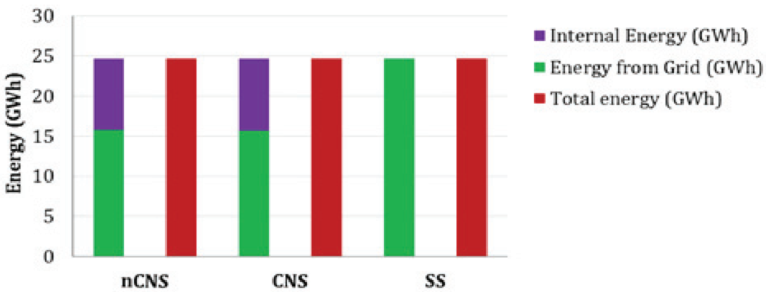

Fig. 6. Leader expected energy demands

Fig. 7 shows the expected economic decisions of the leader manufacturing SC. The nCNS results in 0.4 % and 36.4% savings in the expected energy purchase cost from the local Grid, compared with the CNS and SS cases, respectively. Furthermore, the nCNS results in 2 % savings in the RM purchase cost, compared with the CNS. The inventory economic decisions record 40.5 % and 31.5 % savings, compared with the CNS and SS, respectively, and the distribution cost results in 3.3 % savings, compared with the SS. It is worth mentioning that the total RM purchase cost using the CNS is 2 % higher than using the nCNS, because, unlike the nCNS, the CNS does not give enough freedom to the leader to choose the cheapest RM options and prices.

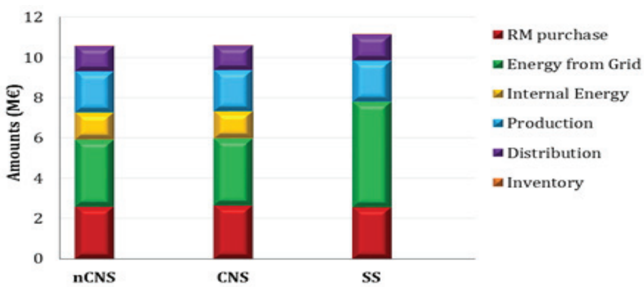

Fig. 7. Leader expected economic decisions breakdown

5. Conclusions

The coordination of multi-product manufacturing SCs is achieved through negotiations built on expected win-to-win principles. Based on non-symmetrical roles, the client "as leader" designs its offers taking into account the uncertain reaction of the provider "follower", which is modelled as a probability of acceptance. Different negotiation scenarios are analyzed, based on individual and global objectives: i) Standalone Scenario (SS), ii) Cooperative Negotiation Scenario (CNS), and iii) Non-Cooperative Negotiation Scenario (nCNS), resulting in different flexible MINLP tactical models. A comparison between the different models is illustrated through a case study, which coordinates different providers' production SC around a manufacturing SC "leader". The results show that the nCNS leads to higher independent expected benefits; 8 % and 1 % comparing with SS and CNS scenarios, respectively. Furthermore, the negotiation scenarios affect the tactical decisions the leader has to make in order to absorb the risks associated with the follower SC response. The proposed approach is generic enough to be implemented, not only on manufacturing SCs, but also on different PSE systems of different process tasks. The proposed approach is a practical decision-support tool allowing to anticipate the mechanisms different manufacturers may use to modify their relationships with their clients and providers during the optimization procedure, which can be used for further stochastic optimizations based on robustness in order to minimize the risk that each negotiation partner may face.

Acknowledgements

Financial support received from the "Agència de Gestió d'Ajuts Universitaris i de Recerca AGAUR", the Spanish Ministry of Economy and Competitiveness and the European Regional Development Fund, both funding the Project SIGERA (DPI2012-37154-C02-01), and from the Generalitat de Catalunya (2014-SGR-1092-CEPEiMA), is fully appreciated.

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