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# Simplified model for integrated Supply Chains Planning

Miguel Zamarripa, Kefah Hjaila, Javier Silvente and Antonio Espuña

*Chemical Engineering Department, Universitat Politècnica de Catalunya, ETSEIB. Diagonal Avenue 647, 08028 Barcelona, Spain.*
**corresponding author antonio.espuna@upc.edu*

## Abstract

The scope of any Supply Chain management strategy usually takes into account the few single echelons directly linked to the process of interest (raw materials acquisition, market distribution,…) which are assumed to present a previously known behaviour (even this behaviour may include some uncertainty). Decisions based on this limited picture disregard the important information associated to the interaction among different cooperative SCs. This work aims to optimize the overall performance of several SC's in a cooperative scenario acting as an "entire SC". Accordingly, the main features of this entire SC (raw materials SC, production-distribution SC, products and wastes) have been considered. The approach is demonstrated using a case study which integrates an energy poligeneration SC model (RM acquisition, and different production systems in a competitive situation) and the traditional production-distribution SC model (RM acquisition, distribution to production plants, production, and distribution to markets) in a mixed integer non-linear programming model.

**Keywords**: Supply Chain Planning, cooperative management, SCM.

## 1. Introduction

The tactical decision making problem has been successfully studied in the last 20 years; recent approaches intend to integrate typical planning models for novel Process System Engineering (PSE) applications, covering a significant number of issues to be considered in practice, like uncertainty (Balasubramanian et al. 2002), Multi-objective optimization (Bojarski et al. 2009), integration of different decision making levels (Sung and Maravelias 2007), etc. but most of them disregard the effects of interaction (cooperation and competition) among SC's.

But the incorporation of information from the different interacting enterprises in a single process model is essential to rationalize the tactical management of any of these interacting systems, requiring the procurement of RM from different suppliers, the allocation of materials to different plants, or deciding the distribution of products to the final consumers. So the features of each one of the single echelons of the entire SC have to be integrated in a specific model with its own objectives and management practices.

One clear example of this need can be found associated to the field of energy management, especially in "green" energy generation, by integrating in a competitive scenario biofuels gasification and combustion processes, and the exploitation of other energetic resources. The design, planning, and operation decision making of energy networks arise as new challenges for the PSE community (Perez-Fortes et al. 2011 Zamarripa et al. 2011).

This work proposes a mixed integer non-linear programming (MINLP) model able to optimize the overall SC planning in order to deal with the complexity arising the consideration of multiple supply chains with independent objectives, the coordination of requirements and their integration with green energy generation systems.
The proposed solution is based on modeling the main characteristics of multiple echelons (including suppliers, production plants, storage centers, waste, and markets) considering the behavior of each echelon. The resulting model is flexible enough to optimize the overall total cost of the entire SC (Suppliers SC, production SC, waste SC, etc.). Furthermore, it is capable to examine and compare different integration options of different sub-networks coordinating the inputs and outputs of each part.

## 2. Problem statement

*2.1. Planning*

In this work, the typical scope of the SC planning problem has been utilized in order to determine the optimal production, storage, and distribution levels associated with the management of a simple SC network. The selected SC network consists of: suppliers, storage centers, production sites, distribution centers, and customers. The constraints associated to the planning model are: the mass balances, production/ storage/distribution capacities, and suppliers' capacities. The resulting model uses continuous and binary variables (the later ones in order to identify the event of producing a certain item in a certain production period) arising in a MILP model.

The resulting model has been used to minimize the "entire SC" total cost (RM, production, distribution, and storage costs), through the integration of the Energy Generation SC (EGSC) planning model and the Production-Distribution SC (PDSC) management models (one model for each one of the considered echelons).

*2.2. Energy Generation SC (EGSC)*

Nowadays, biomass is ranked as the fourth energy production source after oil, gas and coal, providing approximately 14% of the world's energy needs (García et.al, 2012). Electricity generation based on biomass gasification and combustion has been developed over the last few years creating a great market potential. For this study, the biomass has been used as raw material RM feeding the energy generation plants (gasification and combustion plants).

The energy generation SC (Fig. 1) consists of: RM acquisition, storage, and transformation to electricity. The energy distribution echelon has been disregarded.

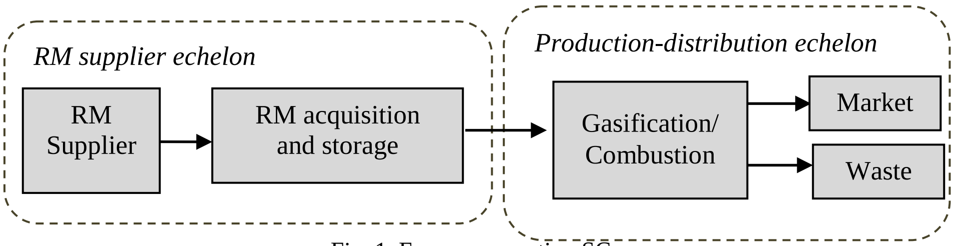


Fig. 1. Energy generation SC.

Equation 1 represents that the total energy provided by generation *p* from raw material *b* to the market *m* at time *t* ($ET_{p,b,m,t}$) should be equal to the markets demand plus the energy demanded by the secondary markets.

$$\sum_p^P \sum_b^B ET_{p,b,m,t} = Dem_{m,t} + E_{m,t} \qquad \forall m, t \qquad (1)$$

*2.2.1. Gasification*

Gasification is a process that turns through a high-temperature partial oxidation of carbonaceous materials to produce syngas, mainly carbon monoxide and hydrogen. The syngas then passes through different treatment steps ended up with a turbine to generate electricity. Various processes technologies are used to produce energy based on gasification: the fixed-bed gasification, the fluidized-bed gasification, and the entrained flow gasification.

*2.2.2. Combustion*

Combustion is a complete oxidation of fuel at high temperatures. The hot gases resulted from the combustion process can be used for heating purposes or passes through generator to produce electricity. Several technologies are used for energy production based on biomass combustion: the steam turbine process, the steam piston engine process, the steam screw-type engine process, the ORC process, and the Stirling engine process (Obernberger and Thek, 2008).

*2.3. Production echelons SC*

A general production echelon SC has been considered (fig-3) consisting on a set of suppliers (raw materials, utilities, etc.), a set of factories, a set and distribution centers, and a set of markets.

Additionally, special attention should be given to accurately model the link to the other associated systems (in this case, the energy systems). Equation 2, used to compute the energy required to maintain the production processes, will be included as key equation in the production echelon model.

$$E_{m,t} = \sum_{pl}^{P} Ener_{pl,t} \qquad \forall m \in Mp, t \qquad (2)$$

$M_p$ represents the set of markets served by the production echelon; $Ener_{pl,t}$ is the energy used to produce one unit (kg) of product; $E_{m,t}$ is the total amount of energy needed from the energy markets.

Other elements can be easily considered in the proposed simplified model. For example, equation 3 estimates the energy needed/associated to the wastewater treatment (WWT). Assuming that a certain quantity of wastewater is generated during the production of polystyrene ($V_{pl,t}$ will represent this load at each time $t$), and the wastewater generated by the energy SC (gasification and combustion processes) at each time period ($W_t$), and given a constant factor *Erate* (kW·h/$m^3$), the WWT energy market demand per time period is calculated.

$$E_{m,t} = \left(W_t + \sum_{pl}^{P} V_{pl,t}\right) \cdot Erate \quad \forall m \in Mw, t \qquad (3)$$

It is worth noting that these additional elements might enforce the introduction of non-linear relations, so in these cases a MINLP model should be finally managed.

Finally, the objective function aims to maximize the profit (Sales - Total Cost), considering the total cost of the polystyrene SC and the Energy generation SC.

$$Profit = Sales - (Pcost + Ecost) \qquad (4)$$

## 3. Case study

The aforementioned concepts have been applied to a case study by integrating different Supply Chains among an entire SC (Fig. 2). The main objective is to produce polystyrene considering a fixed demand from two markets. Combustion and gasification energy plants are used to produce energy from biomass and/or coal to satisfy the demand of four markets: markets m1 and m2: local net and irrigation (fixed demand), market m3: the energy demand by the polystyrene production SC, and market m4: WWT energy demand. The Energy SC is composed of 2 production sites (Gasification p1 and Combustion p2 plants), one RM supplier S1 provides wood pellets b1, Coal b2, petcock b3, and agricultural waste b4. A WWTP (*Erate*=0.43 $kWh/m^3$) is considered to treat the generated wastewater from all SC´s. Energy generation rates have been considered for the Gasification and Combustion processes (0.8-1.2 *kWh/kg* and 3.0-3.6 *kWh/kg*).

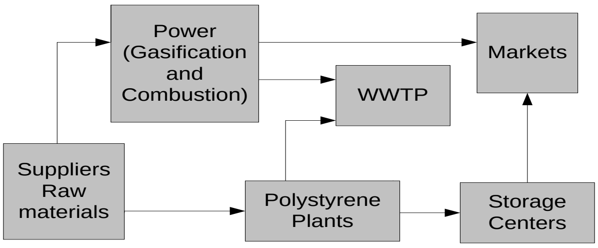

Fig. 2 The “entire SC”

The considered polystyrene SC (Fig. 3) is composed of 4 suppliers of styrene S1, S2, S3 and S4, acquired by 3 production sites (pl1, pl2, pl3) to produce 2 products (polystyrene 97% and 99% purity). These products are stored in two distribution centres (D1 and D2), and then supplied to the markets M1, M2 and M3.

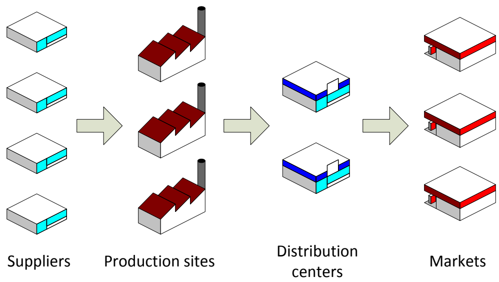

Fig. 3 General Polystyrene production echelon SC Network

Detailed information required to characterize both SC’s (production, inventory, distribution costs; maximum and minimum production/distribution/storage costs; maximum supplier capacity for each raw material, etc.) can be found at https://cepima.upc.edu/contributions/IntegratedSC).

## 4. Results

The solution of the proposed model provides the optimal performance of each SC among the entire SC. Considering material and information flows, processes availability and constraints, and distribution tasks in a time horizon of 14 weeks, the optimal production, distribution and acquisition of raw materials have been obtained through GAMS using DICOPT as MINLP solver. Table 1 shows the optimal quantities of raw materials to be purchased ($Bs_{p,b,t}$) and used ($Bu_{p,b,t}$) from the different suppliers and the corresponding energy requirements ($Pkt_{p,b,t}$) from production plants *p1* and *p2*.
Other optimal solutions are obtained regarding the Energy SC such as: raw material storage levels at each time period; optimal management of the gasification and combustion processes (and corresponding raw material requirements); residues generated (ash, tar, fumes); the detailed energy distribution ($ET_{p,b,m,t}$), etc.

Table-1 RM purchased and used, and energy produced

| | | t1 | | | t2-t4 | | | t5-t9 | | | t10 | | | t11 | | | t12 | | | t13 | | | t14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bs kg | Bu kg | Pkt kWh | Bs kg | Bu kg | Pkt kWh | Bs kg | Bu kg | Pkt kWh | Bs (kg | Bu kg | Pkt kWh | Bs kg | Bu kg | Pkt kWh | Bs kg | Bu kg | Pkt kWh | Bs kg | Bu kg | Pkt kW) | Bs kg | Bu kg | Pkt kWh |
| p1 | b1 | 989 | 1189 | 868 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | b2 | 2300 | 2500 | 5000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | b3 | 5824 | 6024 | 5000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | b4 | 6050 | 6250 | 5000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| p2 | b1 | 1099 | 1299 | 5000 | 13 | 13 | 50 | 9 | 9 | 35 | 128 | 128 | 492 | 1299 | 1299 | 5000 | 1299 | 1299 | 5000 | 1299 | 1299 | 5000 | 1299 | 1299 | 5000 |
| | b2 | 800 | 1000 | 5000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 163 | 163 | 814 | 1000 | 1000 | 5000 | 597 | 597 | 2983 | 67 | 67 | 334 |
| | b3 | 1020 | 1220 | 5000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | b4 | 1050 | 1250 | 5000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1041 | 1041 | 4164 | 0 | 0 | 0 | 0 | 0 | 0 |

Fig.4 shows the energy demand expected from each market ($Em_{m,t}$). Energy plant management and polystyrene plants production levels ($F_{ps,pl,t}$, Table 2) are optimized simultaneously so the polystyrene energy requirements (and such required for wastewater treatment) are coordinated with the requirements from other parties.

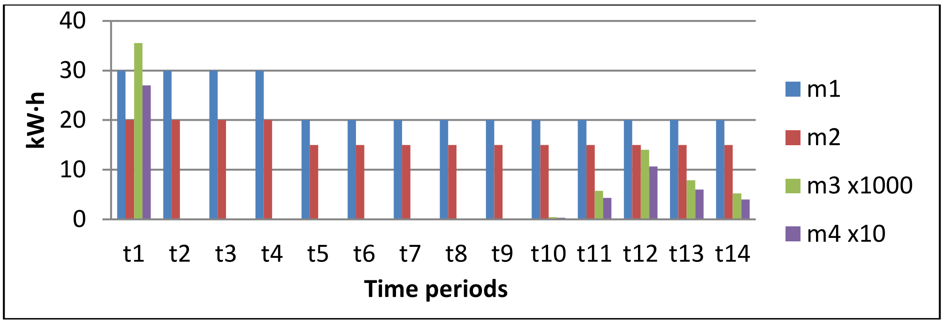


Fig. 4 Energy market demands

Table 2. Production levels (product *ps* in production plant *pl* at time *t*)

| $F_{ps,pl,t}$ | | t1 | t2-t9 | t10 | t11 | t12 | t13 | t14 |
|---|---|---|---|---|---|---|---|---|
| ps1 | pl1 | 940 | 0 | 0 | 0 | 320 | 180 | 120 |
| | pl2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | pl3 | 1080 | 0 | 0 | 10 | 640 | 360 | 240 |
| ps2 | pl1 | 1398 | 0 | 29 | 367 | 605 | 340 | 227 |
| | pl2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | pl3 | 1422 | 0 | 31 | 383 | 355 | 200 | 133 |

Given an expected demand profile from the polystyrene customers (markets *m1-m3*), the optimal results include: styrene to be purchased (raw materials form supplier *sp* to the production plant *pl*, $R_{rm,sp,pl,t}$); transport requirements (product from production plants to distribution centers, $SS_{ps,pl,dc,t}$); corresponding storage levels (product stored at

the distribution center, $St_{ps,dc,t}$) and final distribution levels (products distributed from the distribution centers to the markets, $P_{ps,dc,mk,t}$).
As it can be observed in Fig. 4 and Table 2, the production orders are higher in the first time period in order to reach the safety stock.

## 5. Conclusions

This work proposes a way to coordinate the management of different multi-echelons SC's in a cooperative environment. The solution of the proposed mathematical model provides the optimal acquisition of raw material, production, inventory and distribution levels regarding the considered objective.
The proposed approach adds to the PSE community an important tool towards optimal use of natural resources, optimal energy production, and best industrial production-distribution management. This work provides a novel MINLP model that can be applied to solve and optimize typical SC planning problems.
The proposed model considers the detailed information of each SC echelon as a complete SC among an "entire SC". All the echelons SC's contribute to a cooperative multi SC's optimization. Furthermore, the model integrates the objectives of all echelons SC's among one final objective function.

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