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Supply Chain Design towards sustainability: accounting for growth and jobs

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Abstract

Sustainable supply chain design is nowadays an important topic where not only economic and environmental aspects should be accounted for, but also social aspects are to be considered. A mathematical programming model was developed and a case-study was performed considering two different social indicators: one that prefers facility location in regions of lower GDP and the other in regions of higher unemployment rate. Results show that the outcome depends on the indicator used. However, for the case presented, minimum cost solution also corresponds to a good social solution regarding GDP, which could translate into economic incentives for the company.

Keywords: Sustainability, growth, employment, incentives, supply chain.

1. Introduction

It has become clear that continuing with a development rate such as the one that is practiced today, will most likely lead to an unsustainable situation where our future generations will not be able to meet their own needs, following the definition of sustainable development introduced by the Brundtland Commission (1987). Addressed through a wide variety of disciplines, sustainability is currently a major research topic.

However, to this point, most literature within supply chain sustainability focuses only on the economic and environmental pillars - e.g. Nwe et al. (2010), Furtado et al. (2011), Cucek et al. (2012). Literature on the social pillar is rather infrequent, mainly due to the lack of data and quantifiable social indicators (Brent et al. 2006). Still, research on this field is beginning to emerge (Wang et al., 2011, Mota et al., 2013).

While previously supply chain design decisions would be mainly based on cost/quality, today legislation presses industries to account for other issues. Moreover, company decision makers are beginning to realize that sustainability can actually provide them a competitive advantage. Process industries are not an exception and an investment in sustainable supply chains is to be done (Grossmann, 2004; Barbosa-Póvoa, 2009).

The European Commission has recently released the agenda for the 2014-2020 funding period, with the main focus of fostering economic growth and promoting job creation. The cohesion policy will make available up to €376 billion to invest in Europe's regions, cities and economy. All member states may benefit from the support of the European Commission's funding. However, a distinction between the several regions is made clear as they are categorized according to their level of Gross Domestic Product (GDP) in "less developed" (GDP per capita lower than 75% of the EU-27 average GDP), "transition" (GDP per capita between 75% and 90% of the EU-27 average GDP) and “more developed” (GDP per capita above 90% of the average GDP of the EU-27) regions (European Commission, 2010). Unemployment rate has also served in past periods as an indicator of regional development. Therefore one can assume it to be more likely to receive economic incentives for projects involving job creation in regions with a higher unemployment rate.

This work aims to provide a tool for companies to analyses what level of potential economic incentives would offer them a competitive advantage under the mentioned European Commission funding tools, in the decision of facility location. A mathematical model is developed for the design and planning of closed loop supply chains, which incorporates these economic and social issues.

This paper is structured as follows. In section 2 the problem is defined and the developed model is characterized. Section 3 presents a case study where the proposed model is applied to an European company seeking to expand their business to new European markets. In Section 4 results are presented and analyzed. Section 5 includes final remarks.

2. Modelling Characteristics

The problem addressed in this work aims firstly at determining the supply chain structure along with planning decisions that minimize costs. The problem is modeled through a Mixed Integer Linear Programming (MILP) formulation using a graph approach for the design and planning of supply chains with reverse flows.

The objective function is modelled as shown in Equation (1).

$$Cost = \sum_{i \in I} cf_i Y_i + \sum_{mij:(m,i,j) \in F} \sum_{t \in T} cs_{mit} X_{mijt} + \sum_{ij:(i,j) \in A} \sum_{t \in T} ct_{ij} d_{ij} Z_{ijt} + \sum_{mi:(m,i) \in \tilde{V}_c} cp_{mi} \left(\sum_{j \in I_a} \sum_{t \in T} X_{mijt} \right) + \sum_{i \in I} chr_i Y_i \quad (1)$$

The first term concerns the fixed costs of each entity, controlled by the binary variable Y_i which equals 1 when entity i is opened. The second term accounts for raw materials costs acquired from suppliers where X_{mijt} is a continuous variable for the amount of product m served by entity i to entity j at time t. The third term relates to the costs of transportation which depends on parameters such as vehicle consumption, fuel price and vehicle maintenance. The fourth term represents the costs of product recovery. The fifth and final term concerns the labor costs.

To further study the impact of potential incentives in relocating facilities to regions beneficiary of European funds, a social benefit indicator is developed that favors entities to be located in less developed countries, and can assume different values according to the indicator selected (as GDP per capita, unemployment rate, or any other indicator that fits the problem). This is modelled as shown in Equation (2):

$$SocialBenefit = \sum_{i \in I} \mu_i \times Y_i \quad (2)$$

where μ_i represents the regional factor and Y_i as defined above. For the definition of the regional factor based on GDP per capita, the average GDP of the European Union was used as a level, since it is the value used by the European Commission to assess which countries are considered less developed. For the definition creation of the regional factor based on unemployment rate, the Spanish unemployment rate is used as level, since it is currently the country with the highest unemployment rate in the European Union.

Overall, given a) a possible superstructure for the location of the supply chain entities; b) the investment costs; c) products' bills of materials; d) the relation between forward and reverse products; e) distance between each pair of interacting network agents; f) the minimum disposal fraction; g) the minimum usage time for each return product, h) forward product return fractions; i) the maximum and minimum flow capacities; j) the maximum and minimum acquisition and production capacities; k) the maximum storage capacities; l) the initial stock levels, m) the labor costs of each possible location, q) the social indicator associated to each facility; and for each time period and product, r) customer's demand volume, s) the unit penalty costs for non-satisfied demand and return, t) the unit transportation cost between each pair of interacting network agents; u) the factory acquisition and production unit costs; v) each facility unit storage cost, and x) the unit disposal cost; the goal is to determine 1) the network structure; 2) the production and storage levels: 3) the flow amounts; 4) the non-satisfied demand and return volumes; so as to minimize the global supply chain cost.

3. Case-study

The model was applied to the following process industry case study: company X, which currently owns two factories – one in the United Kingdom and one in Italy – and two warehouses – one in France and the other in the Netherlands - with markets covering Portugal, Spain, France, United Kingdom, Belgium, the Netherlands, Italy, Germany, Check Republic, Austria and Hungary, is planning to expand to seven new markets: Denmark, Sweden, Finland, Romania, Bulgaria and Greece, as shown in Figure 1.

Figure 1. Current network of company X and expected market expansion.

The decision makers of this company are pondering how many warehouses will be necessary to satisfy the expected extra demand at minimum cost. Furthermore they wish to know if locating these extra warehouses in less developed regions, according to the

criteria defined by the European Commission, would be economically viable, considering the potential incentives that would arise.
Company X has a three-echelon closed loop supply chain, as the one shown in Figure 2. The developed model was applied to this supply chain by considering a network super-structure of 2 factories, 18 markets and 18 possible warehouses locations (those corresponding to the markets). The locations of the factories and of the existent warehouses were set as fixed.

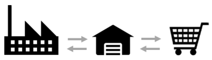

Figure 2. Supply chain structure of company X.

4. Results

In a first step the model was run considering solely cost minimization. Three new warehouses were determined to be necessary to satisfy the expected demand. In a minimum cost perspective those should be: Poland, Bulgaria and Hungary. Having assessed the need for three new warehouses, the model was run again to select the three new warehouse locations that would offer the most social benefit, measured through an indicator obtained from GDP per capita, which returned Poland, Bulgaria and Romania, and through a second indicator obtained through unemployment rate, which returned Portugal, Spain and Greece, as shown in Figure 3.

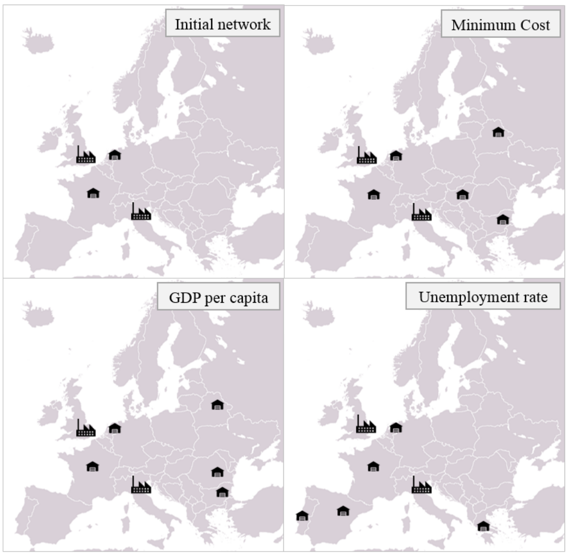

Figure 3. Current network and networks obtained under different objective functions: minimum cost, maximum economic growth cohesion (measured through GDP per capita), and maximum employment cohesion (measured through unemployment rate).

The costs related to each scenario, those that are location dependent (transportation and labor costs), are presented in Table 1.

Table 1. Location variable network costs for the three scenarios considered.

Scenario	Costs for a five year period	Exceeding costs from the minimum cost scenario for a five year period
Minimum Cost	€ 21,287,748	-
GDP per capita	€ 21,477,501	€ 189,753
Unemployment rate	€ 32,415,058	€ 11,127,311

The locations obtained for the minimum cost scenario are actually within the countries identified by the European Commission as less developed regions. Therefore, is this not only the minimum cost solution, as it is likely that the company may benefit from incentives from the European funding. The solution obtained for the maximum social benefit, through GDP per capita, only differs from the first solution by one location – Romania is preferred over Hungary, since the first has a lower GDP per capita. Analysing the costs of this solution one can conclude that with incentives over €190,000, to cover exceeding costs for a five year period, this solution could also be interesting for company X.

Since job creation has been clearly stated as one of the main goals of the European Commission, a social indicator obtained through the unemployment rate has also been defined. However, the results show that the costs associated with the solution with the highest score under this indicator are significantly high – over €11million over a five year period, which is not a viable economic situation for company X. This result was further studied through a multi-objective approach – the ε-constraint method - between costs and this social indicator, as shown in Figure 4. Results show that Spain would be the third location to be considered but that would only be viable with incentives higher than €2.5million, which is very unlikely. This so significant cost gap between different locations is highly motivated by the different average labour costs, which are considerably lower in Bulgaria, Romania, Poland and Hungary (in increasing order).

Figure 4. Multi-objective approach for the minimization of cost with social indicator limitation, with lexicographic optimization.

5. Conclusions

This work proposes a tool for companies to study the potential impact of the European Commission funding on the design of their supply chains. An optimization model for the design and planning of a closed loop supply chain under minimum cost objective is presented. Additionally, two social indicators are developed: one based on GDP per capita and the other based on unemployment rate. Results show that it is important to have such a decision tool as it helps analyzing the level of incentives that would need to exist in order to make relocation to less developed regions economically viable. In the presented case, the outcome is significantly different depending on the indicator used. Following the indicator currently used by the European Commission to measure economic development – GDP per capita – relocating to less developed regions can actually represent lower costs. However, the European Commission itself has recognized that GDP is not, nor it intends to be, an accurate economic development indicator. Still, this methodology can be easily applied to any indicator and might even be used in designing government incentives and in understanding how these actually affect companies. This is an exploratory work and further research is underway to develop more adequate indices and to apply them to different cases.

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