

THE ECONOMIC AND ENVIRONMENTAL ANALYSIS OF A PETROCHEMICAL DISTRIBUTION NETWORK

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Abstract: The structure of a company's distribution network is of vital importance for competitiveness but also involves considerable costs. In recent years, competitive pressure as well as regulatory measures, especially in the European Union, have also raised awareness towards the environmental impact of supply chain activities. However, activities associated with the distribution of products are not yet subject to environmental regulations but this might change in the near future. Therefore, companies will have to consider not only economic but also environmental aspects in the design of their supply chains. Based on a case study from the petrochemical industry we present a way to evaluate (strategic) distribution network design decisions, taking into account economic as well as environmental criteria. The results of the analysis show a clear trade-off between (distribution) costs and transport carbon emissions.

1 INTRODUCTION

Distribution comprises all processes that are necessary to move and store products on their way from the production stage to the customer stage, therefore consisting of transportation and warehousing activities (Chopra and Meindl, 2010). The structure of a company's distribution network is of vital importance as it provides the basis for a high customer service but also involves considerable costs. In particular, decisions concerning the number, location, and capacity of warehouses as well as the allocation of demand are of high relevance in this regard. These decisions are usually driven by companies' urge to gain competitive advantage through reduced costs or improved lead times (Aronsson and Hüge-Brodin, 2006). However, the growing concerns of both governments and customers about environmental protection have also raised awareness towards the environmental impact of supply chain activities. There are already several regulations in force that aim at the reduction of emissions from manufacturing activities, for example the EU Emission Trading Scheme. Yet, activities associated with the distribution of products are not subject to strict regulations with respect to carbon emissions.

One of the industries that is included in the EU Emission Trading Scheme is the petrochemical industry. The process of refining crude oil to final products, for instance gasoline, diesel, or other derivatives like heating oil or lubricant, contributes to climate change to a large extent. In order to tackle the tight regulations, companies have focused on implementing technological innovations to reduce the environmental impact of refinery processes without negatively affecting production costs. As a matter of fact, the topics of distribution network optimization as well as other supply chain related issues have been neglected for a long time by the petrochemical industry (McKinnon, 2004). Only recently companies realized this significant potential for reducing costs (McKinnon, 2005), which has led to several changes in the distribution network of some well known companies. These changes often affect the number of warehousing locations. As a consequence of the restructuring, also the respective primary transport flows from the refineries to the warehouses as well as secondary transport flows from warehouses to the final customers are affected. These distribution network design decisions are usually based on economic criteria (mostly minimization of costs) but environmental aspects, in particular car-

bon emissions from transportation, should not be neglected either.

Based on a case study with one of the leading petrochemical companies in Southeastern Europe, we present a way to combine economic as well as environmental aspects when evaluating (strategic) distribution network design decisions. The company in scope aims at restructuring its distribution network with special focus on reducing the number of local storage locations. For that purpose, we develop an easy-to-use supply chain model that shows the impact of different network scenarios on operational and transportation costs as well as on transport carbon emissions.

2 SUPPLY CHAIN STRUCTURE AND MODELING APPROACH

The company under consideration receives crude oil from three different supply sources. In all cases, the crude oil is transported to one operating refinery via pipeline. Only a negligible share is transported by train. In the refinery, the crude oil is processed into several final products. We focus our analysis on fuel, making no differentiation between gasoline and diesel. After processing, the fuel is delivered to 21 storage locations spread across the country in accordance to the demand in the surrounding area. This so called primary transport is mainly carried out by rail; only one storage location possesses a direct connection to the refinery via pipeline. From the storage locations the fuel is further moved to filling stations, located in 276 cities across the country. The transportation from storage locations to filling stations (secondary transport) is carried out by truck only. It is of importance for the company to supply each filling station from the closest storage location. Concerning transportation to the customers the company aims at minimizing lead time from the storage locations, which can be achieved by the spread of storage locations across the whole country. By pursuing this strategy the company can achieve short (secondary) transport distances and a high service level at the same time. However, this comes at the expense of high costs for primary transport as well as for operating the storage locations.

By reducing the number of storage locations the company tries to reduce total annual distribution costs without any negative impacts on lead time. Total distribution costs consist of primary transport costs, fixed and variable costs of operating the storage locations and secondary transport costs. At the same time the environmental effects of these structural changes

in terms of transport carbon emissions should be assessed. In order to support decision-making, we developed a tool for calculating these costs and the corresponding transport emissions. We wanted to make the application of the tool self-explanatory so that parameters can be changed conveniently and quickly. For that purpose, we decided to use the spreadsheet application Microsoft Excel together with its Visual Basic for Applications (VBA) environment. All necessary data was provided by the company for a representative year.

The model is static and deterministic; the covered time horizon is one year. In a first step, the user of the tool selects the storage locations that should be in operation. We assume that there occur no costs for the closure of storage locations. By letting the user select the locations, actual expert knowledge can be linked with the optimization procedure of the tool. Based on the decision which storage locations are in operation, the total annual distribution costs of the network and carbon emissions from transport activities are calculated automatically. If some of the storage locations in operation are planned to undergo certain steps of revamping in the future, also nonrecurring investment costs are depicted. The calculation minimizes secondary transport costs by assigning the whole demand for each city to the closest storage location in operation. By doing so, the amount of fuel that must be held in stock at each storage location and the corresponding primary transport costs as well as operational costs are determined for each storage location. Given the amount and distance the fuel travels, transport activities are calculated in terms of tonne-km for road and rail transportation. The total transport emissions in terms of CO₂ equivalent (CO₂e) emissions are determined for each mode of transport using conversion factors (based on assumptions about load factors, empty runs, truck types, etc.). This activity-based approach for assessing transport carbon emissions yields good estimations in the absence of detailed process data and is well suited for the (petro-)chemical industry (McKinnon and Piecyk, 2010). The relevant conversion factors were provided by the Finnish Environmental Institute (SYKE, <http://www.ymparisto.fi/>).

3 ANALYSIS AND RESULTS

In the analysis several scenarios were considered which differ only concerning the number of storage locations in operation. Together with the company we decided upon which storage locations should be in operation for each scenario. The Baseline scenario

gives an overview of the current situation and serves as a reference point for comparison. In this scenario, all 21 storage locations are in operation, whereas in the other scenarios the number of operating storage locations is decreased to 17 (Scenario 2), eight (Scenario 3), six (Scenario 4) and three (Scenario 5). From a modeling point of view even a network with only one storage location would be feasible, since no capacity restrictions are included in the model. However, according to the company this is not possible in reality for several reasons like, for instance, too high investment costs or the lack of possible alternatives in case of accidents or breakdowns. The economic and environmental results of the analysis, relative to the Baseline scenario, are summarized in Table 1.

It turns out that a scenario with six storage locations in operation leads to minimal total distribution costs. Obviously, reducing the number of storage locations results in a decrease in operational costs, mainly due to the elimination of fixed costs. Primary transport cost decrease only moderately, also when switching from 21 to six storage locations. This can be explained by the geographical location of the operating storage locations which are strategically located, equally dispersed over the whole country. By doing so, the demanded lead time of two days maximum can still be fulfilled. Only in Scenario 5 with three storage locations primary transport costs drop significantly. The main reason for this is the selected storages being located quite close to each other. Furthermore, the major part of demand in this scenario is fulfilled from the storage location with direct and cheap pipeline supply from the refinery. Thus, primary transport costs are at a minimum. Secondary transport costs increase when the number of storage locations decreases, since the average distance on the road from one storage location to the supplied cities increases with decreasing number of operating storage locations. In the different scenarios the average distance on the road ranges from 72 km (Baseline) to 239 km (Scenario 5). In Scenario 5 the reduction in operational and primary transport costs is outweighed by the drastic increase in secondary transport costs. Therefore, it is generally not possible to say that a reduction of operating storage locations always leads to a reduction in total distribution costs.

Overall transport emissions in the distribution network highly depend on the amount of truck transportation. This is due to truck transportation being by far more carbon intensive than rail transportation. Although the Baseline scenario with 21 storage locations leads to the highest costs, this network structure results in minimal emissions. This can be explained by the importance of rail transport and the compara-

tively low amount of road transport that goes hand in hand with this network structure. As primary transport decreases and secondary transport increases, total emissions of the network also increase and reach their maximum when there are only three storage locations in operation. This highly centralized network consequently necessitates lots of truck transportation. Compared to the Baseline situation, total distribution costs can be reduced by approximately 7.7% while transport emissions are increased by more than 29% in the cost optimal scenario with six storage locations in operation.

Especially in the European Union regulations for carbon emissions from transportation are more and more under discussion. Several options are considered, like imposing a tax on carbon emissions or integrating transport emissions into the already existing EU Emission Trading Scheme. When assuming costs for carbon emissions, a certain amount of money must be paid for each ton emitted by transport activities. In a short analysis we compared the Baseline scenario with maximal costs but minimal emissions to Scenario 4 with six storage locations. It turns out that (*ceteris paribus*) the costs for one ton of CO₂e emissions would have to be approximately 480 Euro in order for these two scenarios to incur the same total distribution costs. Given the fact that currently the costs for one ton of carbon emissions are approximately 16 Euro (on March 28, 2011), the impact of carbon costs in this particular case study can be questioned. However, since this case study cannot be seen as an appropriate generalization over different industries, it is of great importance for future works to observe the ongoing discussions and analyze the impacts of possible policy regulations on a broader scale.

4 CONCLUSIONS

Based on an actual case study we showed the economic and environmental impacts of altering the number of storage locations in a petrochemical distribution network. It turns out that total distribution costs, first, decrease with the number of storage locations because of a reduction in fixed costs and primary transport costs. However, in a highly centralized network increased secondary transport costs compensate the reduction in operational and primary transport costs, resulting in again increasing distribution costs. For the company in consideration a network design with six storage locations in operation (Scenario 4) is most likely to be realized in the near future. Through major revamping actions at the storage locations and through equipping them with up-to-date technology,

Table 1: Economic and environmental results of scenario analysis.

| | Baseline | Sc. 2 | Sc. 3 | Sc. 4 | Sc. 5 |
|------------------------------------|-----------------|--------------|--------------|--------------|--------------|
| Number of storage locations | 21 | 17 | 8 | 6 | 3 |
| Operational costs | 100 | 86.6 | 71.7 | 59.0 | 39.8 |
| Primary transport costs | 100 | 100.4 | 98.2 | 94.2 | 48.9 |
| Secondary transport costs | 100 | 102.3 | 126.6 | 141.1 | 233.2 |
| Total distribution costs | 100 | 95.0 | 95.0 | 92.3 | 93.5 |
| Primary emissions | 100 | 98.6 | 93.1 | 90.6 | 35.7 |
| Secondary emissions | 100 | 106.5 | 161.5 | 192.9 | 385.2 |
| Total emissions | 100 | 101.6 | 119.1 | 129.4 | 168.2 |

the coordination between the locations shall be improved and warehousing costs shall be reduced, taking advantage of scale economies. Although the negative impact of this scenario on carbon emission is apparent, environmental criteria do not play any role in the decision-making in this particular case. Several reasons for this can be considered, however the most important one is the fact that transport emissions do not have negative financial consequences for the company at the moment. As long as there are no further costs for transport emissions, the increase in emissions will be compensated by the reduction of operational and primary transport costs.

The analysis shows a clear trade-off between costs and carbon emissions. Minimal costs are achieved with only a small number of operating storage locations, but this drastically increases carbon emissions. In contrast to this, minimal emissions are achieved in a highly decentralized distribution network, but only at very high costs. It is interesting to see, however, that in this case study a deviation from the cost optimal situation does not lead to drastic changes in total distribution costs. For example, when switching from a network with six storage locations (Scenario 4) to a network with 8 storage locations in operation (Scenario 3), total distribution costs increase only slightly compared to the cost optimal design, but notable improvements in total carbon emissions can be achieved. Therefore, further analyses concerning the sensitivity of distribution network optimization results with respect to costs and carbon emissions are mandatory.

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