Tax-related aspects of logistics network planning: a case study in the Brazilian petrochemical industry

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Tax-related aspects of logistics network planning: a case study in the Brazilian petrochemical industry

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This study investigates the logistics network planning in a major Brazilian petrochemical company, taking into consideration the impact of tax-related costs, in addition to transportation and inventory costs. A Mixed Integer Nonlinear Programming model that considers the most relevant costs involved in the network planning process in Brazil was developed and subsequently applied to a case study of a large Brazilian petrochemical company. Our results support anecdotal reports regarding Brazilian companies intensely using ‘product tourism’ to take advantage of different interstate tax rates. Product tourism occurs when a logistically unnecessary flow of goods is established to a lower tax jurisdiction (with a corresponding increase in transportation costs) so that the company obtains a reduction in the amount of the taxes due.

Keywords: Brazil; logistics network planning; mixed integer nonlinear programming; petrochemical industry; tax-related costs

1. Introduction

Given the growing complexity of logistics-related issues in a highly interconnected world, the design and planning of logistics networks can be an important lever for companies in their quest to achieve higher levels of competitiveness. Traditionally, companies have sought to make sound strategic decisions to balance their uncertainties and risks, service levels and, logistics network costs (Wanke and Zinn 2004). Recently, though, it has become increasingly clear that the designing and planning of logistics networks should, as much as possible, consider an even broader end-to-end holistic approach by taking into account not only the traditional logistics variables (i.e. those related to distances), but also transportation volumes and costs. Other intervening variables that may influence the company’s overall financial performance when adopting a certain network design should also be considered. One relevant example relates to the tax-related aspects of logistics. Tax structures (and resulting costs for the company) are important contextual mediating factors that may substantially alter the effectiveness of location decisions and network design and planning.

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Tax-related logistics costs and traditional logistics costs (e.g. warehousing, transportation) may represent important trade-offs that require careful managerial consideration when deciding about logistics networks (Yoshizaki 2002; Avittathur, Shah, and Gupta 2005; Drtina and Correa 2011).

1.1. Logistics network design and planning

Planning logistics networks means determining the number of facilities (e.g. manufacturing plants and warehouses), their location, and the definition of what consumer markets will be primarily served by each of them.

A general network planning problem involves a set of spatially distributed customers and a set of facilities that aim to serve said customers’ demands (Melo, Nickel, and Saldanha-da-Gama 2009). This stands out as one of the most important decisions in logistics strategic management as these decisions involve considerable capital investments and have a direct impact on customer service levels as well as logistics total cost since they drive most decisions on warehousing, inventories and transportation.

Davariz (2006) states that costs associated with changing a poorly designed logistics network can be very high as they involve decisions that are usually costly to change, such as the location and capacity of facilities. On the other hand, given the potential impact of a better network design on the company’s operating cost, periodic redesigns may be worthwhile. Ballou (2001), for instance, estimates that a good logistics network redesign exercise backed by sound optimising techniques could save the company 5–15% in total logistics operating costs. It is thus important for a company to periodically re-evaluate its existing logistics network design so that its footprint reflects possible changes both in environmental (e.g. fuel price and tax structure changes) and internal (e.g. changes in supply chain strategies and mergers and acquisitions) intervening factors.

1.2. Coping with tax structures when designing logistics networks in Brazil

One environmental aspect that has recently gained increased priority in Brazilian managers’ agendas is the domestic tax structure. This is because of the recent discussions in Brazilian Congress to review the country’s deficient fiscal system that is too complicated and costly to deal with and too ineffective to support a growing economy (Yoshizaki 2002). This is by no means a problem that only affects Brazil. Discussions on tax reform have also been amongst the most controversial themes discussed in recent presidential campaigns in the USA and Mexico, to name a few.

Once goods cross borders (between local tax jurisdictions: cities, states, regions and/or countries) to be transferred between locations, complicating tax issues arise, such as import taxes, different corporate tax, value-added tax and sales tax structures (Goetschalckx, Vidal, and Dogan 2002; Meixell and Gargeya 2005; Tsiakis and Papageorgiou 2008; Das and Sengupta 2009).

Studying the differences in corporate income taxes between tax jurisdictions and their effect on the offshoring location decisions of multinational companies, Drtina and Correa (2011) conclude that in order to make informed supply chain logistics network decisions, managers should include in their decision calculus the effects of transfer pricing on divisional tax rate differentials. Failure to do so would mean that expected gains projected by otherwise sophisticated models may be siphoned off by tax obligations and thus never realised by the corporate entity as a whole. The authors believe that, given its importance, tax effects should be included as an added variable when developing quantitative location studies. They argue that more research is needed to determine how tax consequences should enter the supply chain model.

To contribute to this debate, this study proposes a mathematical programming model to be used in logistics network planning for situations such as the Brazilian case – where value-added tax
rates vary by state (a situation also found in many other regions such as the European Union). Our study considers not only transportation- and inventory-related costs but also tax-related aspects in designing logistics networks.

After developing the mathematical model, including assumptions that are consistent with the Brazilian tax environment, it was subsequently applied to the real case of the Brazilian petrochemical company Nova Braskem (www.braskem.com.br).

Besides providing guidelines for a potentially optimal re-designed configuration and operation of the Nova Braskem logistics network, objective estimates of potential financial gains obtained by applying the results of the model were drawn from the analysis. Additionally, sensitivity analyses were performed in order to identify possible trade-offs between the main cost components involved (e.g. trade-offs between tax-related costs and transportation- and inventory-related costs).

This paper is divided into five sections. Following the introduction, the second section critically examines the relevant literature and relevant aspects of the Brazilian tax. The third section briefly discusses the applicability of the model in other regions of the world. Section 4 introduces the proposed model and describes the parameters used to apply the model to the Nova Braskem case. Section 5 discusses the main results of the study, analyses scenarios, and discusses the sensitivity analyses performed. Section 6 focuses on conclusions, limitations, theoretical and managerial implications, and proposes some avenues for further research on the topic.

2. Logistics network planning and selected tax aspects in Brazil

Logistics network planning (also called network design) constitutes one of the most important aspects of the logistics planning process. It involves determining the structure (also called the logistics footprint) of the chain through which products will flow from points of production to points of consumption. In determining the said structure, trade-offs should be considered in a way that appropriately balances customer service and suppliers’ cost and profitability objectives.

According to Ambrosino and Scutellà (2005), logistics network planning is a problem that involves determining the best way to transfer goods from points of supply to points of demand and designing a network’s structure (i.e. the number of network facilities or ‘nodes’ and their location, operations to be performed in each node, and links between them) in a way that minimises total network costs. Lacerda (2000) suggests that, given the interdependency between decisions regarding network design, they should not be made in a segmented or localised fashion. Rather, if a company intends to adopt an end-to-end approach to supply chain management decision costs, then it should make network design decisions in a comprehensive holistic fashion by simultaneously considering the most relevant intervening factors.

According to Bowersox, Closs, and Cooper (2006), trade-offs occur between supply chain cost elements because of their different behaviour patterns. For example, there may be trade-offs between (the chosen mode of) transportation cost and inventory holding costs or between tax-related costs and transportation/inventory costs (Figueiredo, Fleury, and Wanke 2003).

Network design should thus attempt to find a logistics network that minimises total cost while observing minimum service-level restrictions (Figueiredo, Fleury, and Wanke 2003; Ambrosino and Scutellà 2005).

This study focuses on the Brazilian state tax on the ‘circulation’ of goods and services (internally called ‘Imposto sobre Circulação de Mercadorias e Serviços’, ICMS), a very relevant tax that collects the equivalent of approximately 7.5% of the Brazilian GDP (Yoshizaki 2002); ICMS is a value-added indirect tax that falls within the jurisdiction of Brazilian states and is levied on transactions associated with the circulation of goods, people and services where tax is levied by the state in which the buyer is located (Zanluca 2010).
According to Yoshizaki (2002), the ICMS tax structure has had a considerable impact on logistics network planning and thus on logistics costs in Brazil. ICMS is a state-level tax and its rate varies according to the state in which the taxable transaction occurs.

Tax rates levied in export operations and national limits for the maximum and minimum tax rates to be applied on inter-state operations are pre-established by Brazilian Federal law; however, intra-state tax rates are determined by the states, observing said pre-established limits. Thus, each Brazilian state can have a different tax rate for each product category and/or commercial operation (e.g. purchase, sale and simple transfer). Table 1 presents current intrastate and interstate taxes for the 27 Brazilian states, according to the Brazilian National Finance Policy Council (CONFAZ), which is the government body responsible for establishing limits for ICMS tax exceptions granted by individual states.

ICMS is a typical value-added tax, calculated as follows:

\[
\text{ICMS} = [\text{Value of product or service sold} \times \text{TaxRate where product or service was sold}]
\]

\[
- [\text{Value of inputs used to produce the product or service} \times \text{Tax rate where inputs were acquired}].
\] (1)

In principle, a company can take two general courses of action in relation to any tax savings obtained: (a) the company passes all or part of the tax savings on to consumers in the form of a price reduction in an attempt to gain market share or (b) the company keeps tax savings advantages by using them to increase its profits.

In Brazil, in some instances, tax savings obtained by utilising skillful fiscal/logistical special arrangements are so significant that, from the viewpoint of companies, they sometimes justify considerable increases in logistics costs that may result from locating units in more distant states that have lower tax rates. In other words, within ICMS’s current structure (with very different value-added tax rates defined by different states), companies can obtain substantial savings by avoiding (or reducing) payable taxes by locating facilities in lower-ICMS tax jurisdictions – even if this means spending more on logistics.

Table 1. Intrastate and interstate tax rates.

<table>
<thead>
<tr>
<th>ICMS Tax rates (%)</th>
<th>DESTINATION (different states in Brazil)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>AC</td>
</tr>
<tr>
<td>States</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>
| Source: CONFAZ (2013).
Individual states tend to use their autonomy in defining ICMS tax rates (though within federally defined limits) to manipulate them so that they create incentives for companies to localise facilities in their territory, thereby increasing their individual state tax revenues (and possibly, as a desirable side effect, leveraging job creation in the state). There are various examples that illustrate these state strategies for this big-stakes game. Just to mention one, the large and state-of-the-art Ford plant located in the state of Bahia, in the northeast of Brazil, was initially planned to be located in the southernmost state of Rio Grande do Sul. After a fierce fiscal war between the two states bidding by offering more and more tax incentives to Ford Motor Co., Bahia eventually won the US$780M investment, 8000 direct jobs, and an estimated 80,000 indirect jobs, and started production of 250,000 vehicles per year in January 2001.

Under these circumstances, ICMS tax avoidance/reduction becomes an important intervening factor in network design. In Brazil, this is sometimes achieved by ‘product tourism’, whereby a logistically unnecessary flow of goods (with a corresponding increase in transportation costs) is determined to a facility in a lower tax jurisdiction location (established there by the interested company exclusively to qualify for the tax advantage) before being shipped to the final destination. This way, the company obtains savings by reducing the overall amount of ICMS tax paid (Cassone 1995).

Companies often consider that the increased marginal transportation costs resulting from the product’s unnecessary trip to a lower-tax jurisdiction facility must not exceed the tax-related savings, and that the customer service level provided should not be jeopardised by the increased lead times. Needless to say, in order to keep service levels unharmed even with increased lead times, higher inventory levels may be required, which may in turn further increase logistics costs.

In addition, the concession of ICMS exemptions, deferrals, incentives and benefits is the prerogative of the individual states provided that they are approved by CONFAZ. To add to the problem, Calciolari (2006) observes that states currently grant benefits and incentives outside the control of CONFAZ.

The objective of the states that manipulate the ICMS tax rates, as stated above, is to attract investments in order to supposedly leverage regional development and job creation (on top of the more obvious benefit of increasing state tax revenues).

These types of policies have been used in such an aggressive way by the Brazilian states that they often end up being known as tax wars between states that are in competition for investment and tax revenues. One could argue that such subsidies are unfair and possibly detrimental to free competition because they give an unfair advantage to companies that have had access to said benefits.

On the other hand, from the viewpoint of individual businesses, tax wars can have a positive financial effect because they involve a certain level of tax-based subsidies for establishing facilities in certain states.

In this sense, as suggested by Melo, Nickel, and Saldanha-da-Gama (2009), mathematical models for facility location should be used that enable decision-makers to appropriately analyse all of these intervening variables simultaneously.

In addition to all of the aforementioned reasons, it is worth noting that tax rates in Brazil are very volatile. In an attempt to be more effective in attracting investment and tax revenues, states incessantly manipulate their tax rates in order to enhance their benefits. In fact, this has been such a problem in Brazil that the Brazilian Supreme Court recently ruled that all unilateral tax incentives and exemptions that are implemented by states without being previously approved by the federal government (CONFAZ) are unconstitutional; however, this does not mean that tax incentives and exemptions will not be approved by CONFAZ. Whenever these tax rates are substantially altered in the state where a company operates, a review of its current logistics footprint location decisions should be in order. This task can be substantially facilitated by mathematical models such as the one proposed in this paper.
Table 2. Facility location models that do not consider inventory maintenance costs.

<table>
<thead>
<tr>
<th>Main contributions</th>
<th>Author</th>
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</thead>
<tbody>
<tr>
<td>$p$-Median model that seeks to determine the location of $p$ facilities (without capacity limit and with pre-established locations) that minimises the total average distance between them and demand points. In sum, the problem’s objective is to minimise total transportation costs</td>
<td>Hakimi (1964)</td>
</tr>
<tr>
<td>Model that considers the problem of coverage in order to minimise the fixed cost of opening facilities, taking into account: distances/maximum delivery times and the minimum number of facilities necessary to meet all demands</td>
<td>Hakimi (1965), Owen and Daskin (1998), Minieka (1970), Elzinga and Hearn (1972), Brandeau and Chiu (1989)</td>
</tr>
<tr>
<td>Model derived from the previous one that considers the problem of maximum coverage, in which the coverage possible is restricted to a maximum number of pre-defined facilities. The aim is to meet all demand</td>
<td>Church and Revelle (1974)</td>
</tr>
<tr>
<td>Model that considers the minimax or $p$-centre problem in order to minimise the maximum distance between demand points and the facilities closest to them. An analysis of studies performed by various authors revealed two main variations of this problem: in the first – Vertex Centre Problem – facilities can only be located at specific network nodes, whereas in the second – Absolute Centre Problem, facilities can be located at any position in the network. The authors also present a model that considers the fixed costs of opening facilities without capacity – the Fixed Charge Facility Location Problems. They are derivations of $p$-medians where the cost of opening a facility is added and the restriction on the number of facilities that can be opened is relaxed</td>
<td>Owen and Daskin (1998)</td>
</tr>
<tr>
<td>Model that considers restrictions on facility capacity, limiting a facility’s ability to meet demand to its capacity, known as Capacitated Facility Location Problems</td>
<td>Miranda and Garrido (2004), Nozick and Turnquist (2001)</td>
</tr>
</tbody>
</table>

Table 3. Facility location models that consider simplified inventory maintenance costs.

<table>
<thead>
<tr>
<th>Main contributions</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLITNET (Facility Location, Inventory, Transportation and Network) model classified as a Mixed Integer Linear Programming model (MIP)</td>
<td>Jayaraman (1998)</td>
</tr>
<tr>
<td>Model that also considers inventory-related costs. The logistics network is composed of four different levels: Level 1: a single factory with an unlimited capacity that is responsible for supplying the subsequent link constituted by central warehouses; Level 2: group of potential central warehouses responsible for supplying the next two levels – regional warehouse/transit points (TPs) and the demand nodes, classified into customer and big customers; Level 3: group of regional warehouses and TPs that dispatch goods to customer and big customers; Level 4: composed of all demand nodes</td>
<td>Ambrosino and Scutellà (2005)</td>
</tr>
<tr>
<td>Model adapted from Jayaraman (1998) for a biodiesel supply chain that promotes a multi-period optimisation in two dependent and subsequent time intervals</td>
<td>Davariz (2006)</td>
</tr>
<tr>
<td>Model that relaxes some of Jayaraman’s (1998) restrictions and separates the decisions related to factory/warehouse and warehouse/market transportation</td>
<td>Martos and Yoshizaki (1999)</td>
</tr>
</tbody>
</table>

Current network design models found in the literature can be divided into those that, on top of transportation costs: (a) do not consider inventory maintenance costs (Table 2); (b) consider inventory holding costs in a simplified fashion (Table 3) and, (c) consider inventory holding costs (Table 4). Basically, we considered the historical evolution with respect to the methodology used until we reached location models that consider inventory-related aspects in several ways.

This study proposes a model that, in addition to considering inventory holding cost based upon centralisation effects, also considers the effect of taxation.

To better understand facility location models that consider inventory centralisation effects, it is useful to revisit the nature of these effects. Below, the portfolio effect (PE) and the consolidation effect (CE) are reviewed.

- PE: Zinn, Levy, and Bowersox (1989) defined PE based on the Square Root Law that had been developed by Maister (1976). The PE measures the per cent savings obtained by centralising
Table 4. Facility location models that consider the effects of inventory centralisation.

<table>
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<tr>
<th>Main contributions</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model whose aim is to maximise the PE by minimising safety stock through inventory centralisation. Based on the study’s conclusions, the authors emphasise the need to consider safety stock-related costs.</td>
<td>Das and Tyagi (1999)</td>
</tr>
<tr>
<td>Model based on a classic location model – fixed costs of facilities operation and transportation costs – which considers inventory maintenance costs related to safety stock. Using the square root law (Maister 1976) to model inventory, the authors are able to eliminate the nonlinearity related to it and thus use the original model’s assumptions.</td>
<td>Croxton and Zinn (2005)</td>
</tr>
<tr>
<td>Model whose aim is to determine a logistics network’s best configuration based on directly determining the allocation of consumer market demand to available facilities. As one can observe, its distinguishing feature is that it considers cycle and safety stock. In addition, three of its main assumption should be highlighted: (1) different market demands are not correlated; (2) each market should be served by only one facility; (3) the inventory management model used is economic order quantity and reorder point.</td>
<td>Das and Tyagi (1997)</td>
</tr>
<tr>
<td>Model that considers cycle and safety stock management costs and whose assumptions are less restrictive than those used by Das and Tyagi (1997). In addition, total network cost includes costs related to order placement, replenishment and distribution to markets. In contrast to Das and Tyagi (1997), any market can be supplied simultaneously by multiple warehouses.</td>
<td>Montebeller Jr. (2009)</td>
</tr>
</tbody>
</table>

safety stocks. Upon using their formulation, the authors concluded that PE is not directly affected by the absolute values of the standard deviation of demand on facilities, but by the relation between them. Mahmoud (1992) worked on the generalisation of the PE concept introduced by Zinn, Levy, and Bowersox (1989). The same author subsequently proposed the Portfolio Quantity Effect (PQE) that measures the reduction in the quantity of safety stock produced by the PE (Wanke 2009).

• CE: Evers (1995) incorporated cycle stocks into the formulation of PE and defined CE as being composed of two distinct components: PE related to safety stock, and Order Quantity (OQ) related to cycle stock (Wanke and Saliby 2009).

Wanke (2009) and Wanke and Saliby (2009) argue that facility location problems should also include inventory centralisation models that present a less-restrictive formulation by considering possible correlations markets, demand and replenishment lead-time uncertainties and cycle and safety stock costs in a nonlinear fashion, and . This could introduce greater flexibility in inventory allocation decisions, thereby enabling markets to be served from multiple facilities (Jang et al. 2002; Melo, Nickel, and Saldanha-da-Gama 2006; Vila, Martel, and Beauregard 2006).

The present study goes one step further by proposing a facility location model that considers the effects of taxes. More precisely, the proposed model is currently being used to assess Brazilian domestic logistics networks, departing from previous studies as shown in Table 5.

3. VAT-type taxes in other parts of the world

Although our model was developed and applied to a case in Brazil, below we briefly describe the use of VAT-type taxes in selected countries and regions of the world so that we better understand the generalisability, applicability and usefulness of the model we developed in this research.

3.1. European union

According to the European commission, ‘the VAT (value-added tax) Directive1 provides a legal framework for the application of VAT rates in Member states. Member states have made and
The model developed is based on a location model proposed by Geoffrion and Graves (1974), in which the logistics network is composed of three links: factories, warehouses and markets. The problem’s boundary conditions are listed as follows: (1) each factory produces only one product line; (2) each factory has the capacity to meet total demand for these products; (3) the locations of these factories are fixed and pre-determined; (4) potential locations of warehouses are pre-determined; (5) total demand for each product should be satisfied; (6) processing performed at each warehouse should not exceed the capacity associated with its fixed annual costs; (7) physical distribution is undertaken with the support of a logistics operator; (8) deliveries can be made directly from factory depots to retailers, or through warehouses; (9) a market can be served by various warehouses or directly from the factory; (10) important markets are served according to pre-determined schedules; (11) each market is constituted by retailers who desire ICMS credit (they do not evade tax) and by retailers who are indifferent to the credit (they may evade tax); (12) the model considers only the finished products chain and excludes the ICMS on the value added to merchandise due to the transformation process; (13) it does not consider the system’s inventory costs. The objective function is composed of four parts, with three related to the network’s transportation costs during the following flows: factories to warehouses and factories to markets; and one to warehouse opening and operation. Finally, based on his case study, Yoshizaki (2002) verifies that, in the case of Brazil, the trade-off between logistics costs and taxation (ICMS) influences network planning and thus cannot be ignored.

Yoshizaki (2002) verified the effects of ICMS based on the application of a simplified version of Yoshizaki’s (2002) model. Drawing on Yoshizaki (2002), the author proposes a logistics network planning model that, as well as the taxes related to merchandise circulation, includes considerations on the effects of tax incentives based on ICMS presumed credit. Applied the original 2002 model to assess the ICMS’s new rate structure, which is scheduled to become completely effective in 2016, and concluded that the reduction in ‘merchandise tourism’ will be negligible. Extended Yoshizaki (2002) and Silva (2007), with a facility location model that considered: fixed and variable costs of distribution centres and factories, transportation costs (transfer and distribution flows), tax benefits and environmental costs (carbon credits). The conclusions regarding trade-offs between logistics and domestic tax structure confirm the findings of the other authors mentioned above. However, environmental costs did not have a significant influence. This model adopts a more simplified approach to tax aspects/taxation compared to other authors. However, as it includes the most relevant tax aspects, it was quite adherent to business reality.

Table 5. Facility location models that consider the effects of Brazilian tax system.

<table>
<thead>
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<tbody>
<tr>
<td>Drawing on Yoshizaki (2002), the author proposes a logistics network planning model that, as well as the taxes related to merchandise circulation, includes considerations on the effects of tax incentives based on ICMS presumed credit</td>
<td>Silva (2007)</td>
</tr>
<tr>
<td>Applied the original 2002 model to assess the ICMS’s new rate structure, which is scheduled to become completely effective in 2016, and concluded that the reduction in ‘merchandise tourism’ will be negligible</td>
<td>Yoshizaki, Hino, and Rosin (2008)</td>
</tr>
<tr>
<td>Extended Yoshizaki (2002) and Silva (2007), with a facility location model that considered: fixed and variable costs of distribution centres and factories, transportation costs (transfer and distribution flows), tax benefits and environmental costs (carbon credits). The conclusions regarding trade-offs between logistics and domestic tax structure confirm the findings of the other authors mentioned above. However, environmental costs did not have a significant influence</td>
<td>Carraro (2009)</td>
</tr>
<tr>
<td>This model adopts a more simplified approach to tax aspects/taxation compared to other authors. However, as it includes the most relevant tax aspects, it was quite adherent to business reality</td>
<td>Wanke, Montebeller Jr., and Tardelli (2010)</td>
</tr>
</tbody>
</table>

continue to make wide use of the possibilities offered within this framework; as a result, the situation is in practice disparate and complex.

The basic rules are simple:

- Supplies of goods and services subject to VAT are normally subject to a standard rate of at least 15%;
- Member states may apply one or two reduced rates of not less than 5% to goods and services enumerated in a restricted list;

These simple rules are, however, complicated by a multitude of derogations granted to certain member states, and in some instances a majority of member states. These derogations were granted during the negotiations preceding the adoption of the VAT Rates Directive of 1992 and in the Acts of Accession to the European Union. Overall, such derogations prevent a coherent system of VAT rates in the European Union from being applied.

When analysing the VAT standard rates, they range from 15% in Luxembourg to 27% in Hungary.

As the mechanism of the European VAT is similar to that of the ICMS in Brazil, with different constituent states defining different VAT taxes for their jurisdictions, the basic concept of our
proposed model can be as useful for Europe as it is for Brazil, at least before the European Union decides to level the VAT rates of all constituent states.

3.2. Mexico

Mexico uses VAT with a 16% tax rate for most of the country, but with a reduced 11% rate at the border and some other areas.

3.3. China

According to the Chinese Ministry of Finance (accessed 18 June 2013), In China VAT is administered by the State Administration of Taxation, and the revenue from it is shared between the central government (75%) and local governments (25%). VAT is the major source of fiscal revenue for the Government of China, particularly the central government. China established a country-wide standard value-added tax in 1984 with a standard tax rate of 17% (with a reduced rate of 13% for some products and total exemption for others, such as agricultural products). Russia (18% rate), Argentina (21% rate), Nigeria (5% rate), Pakistan (16% rate), Indonesia (10% rate), Switzerland – all cantons (8% rate) are also examples of countries that adopt VAT-type taxes, but that use a standard tax rate for all states or sub-regions.

3.4. India

The VAT in India is ‘basically a State subject, derived from Entry 54 of the State List, for which the States are sovereign in taking decisions. India works with standard VAT tax rates across all the adopting states. At present, there are 2 basic rates of VAT, namely, 4% and 12.5%, besides an exempt category and a special rate of 1% for a few selected items. The items of basic necessities and goods of local importance (up to 10 items) have been put in the zero rate bracket or the exempted schedule’, according to the Business Knowledge Resource Online of the Indian Government. http://business.gov.in/taxation/vat.php (accessed 18 June 2013).

3.5. USA

The USA does not levy a federal value-added tax or sales tax. Individual states levy sales tax (not a value-added tax, once it is paid to the governing body only at the point of sale) at various rates subject to state-set requirements. Our proposed model, therefore, however applicable to the USA will probably not be as useful in terms of considering value added tax in location decisions.

To summarise, our proposed model in principle applies to all countries and regions but it will be most useful to analyse situations in which VAT-type taxes are used and that allow different constituent states or sub-regions to define their VAT taxes independently (as in the European Union, Mexico and Brazil).

4. Proposed model

The proposed model draws from the CE (because of the centralisation of cycle and safety stocks into fewer locations), as proposed in Wanke (2009) and Wanke and Saliby (2009), and also from location models presented in Melo, Nickel, and Saldanha-da-Gama (2009). We adjusted some of their original assumptions so that our model would better adhere to the modelled reality. This is one of the original contributions of our model.
The proposed logistics network is composed of three ‘stages’: factories, warehouses, and consumer markets.

The network’s total cost is comprised of the following:

\[
TC_{\text{Network}} = TC_{\text{Replen}} + TC_{\text{Dist}} + TC_{\text{CS/OP}} + TC_{\text{SS}} + TC_{\text{ICMS}},
\]

where \(TC_{\text{Network}}\) is the total network cost, \(TC_{\text{Replen}}\) the total warehouse replenishment cost, \(TC_{\text{Dist}}\) the distribution to market cost, \(TC_{\text{CS/OP}}\) the cycle stock holding and order placement cost, \(TC_{\text{SS}}\) the safety stock holding cost, \(TC_{\text{ICMS}}\) the ICMS-related tax cost.

Distribution to market cost \((TC_{\text{Dist}})\) is composed of two distinct parts: the first relates to supplying consumer markets directly from factories, and the second relates to echeloned distribution through warehouses. This is represented in Equation (3):

\[
TC_{\text{Dist}} = TC_{\text{Distfact}} + TC_{\text{DistW}},
\]

where \(TC_{\text{Distfact}}\) is the cost of direct distribution from factories and \(TC_{\text{DistW}}\) the cost of distribution through warehouses.

As per the last part of \(TC_{\text{Network}}\), it calculates the network’s ICMS balance due (because ICMS is a value-added tax), thus:

\[
TC_{\text{ICMS}} = \text{Debits} - \text{Credits}.
\]

Debits are generated by flows of goods from factories to warehouses/markets and from warehouses to markets, and credits are those (aggregated) tax values paid by factories (related to their purchases of raw material and components) and warehouses (related to taxes paid when goods were purchased). The formulation of the taxation aspects was developed based on the one proposed by Wanke, Montebeller Jr., and Tardelli (2010). As a methodological note, it should be pointed out that credits are considered as an input parameter in the factory because, at this point in the logistics chain, they are due to the supply of raw materials, which is beyond the scope of this model. Therefore, some estimates of the credits generated by this operation had to be considered as input parameters.

In the proposed model, markets can be served by more than one warehouse (cross-filling). The model also considers cycle stocks, safety stocks, possibly correlated demands, and replenishment lead-time variability – all simultaneously. It is, therefore, different from those found in the current literature because: (a) differently from this model, the consideration of inventory-related costs in most location models in literature is oversimplified (such as assuming linear relations) or neglected altogether; (b) the consideration of the tax-related aspects is present here but generally not in models found in literature; and, (c) the consideration of multiple factories/products, direct distribution from factories and tax-related aspects in this model makes it less restrictive and more adherent to the modelled reality. The mathematical formulation is presented next.

**Sets:**

- \(i, l\) = market index,
- \(j\) = index of warehouses in the network,
- \(f\) = factory index,
- \(p\) = product index.

**Parameters (in brackets: the unit of measurement):**

- \(n\) = total number of markets,
- \(m\) = number of possible locations for a warehouse,
- \(k\) = total number of factories,
- \(r\) = total number of products,
Aa_{fjp} = \text{unit cost of placing an order for product } p \text{ in warehouse } j \text{ from factory } f \text{ ($/order)},

Ca_{jp} = \text{cost of holding inventory of product } p \text{ in warehouse } j \text{ ($/unit)},

Db_{ip} = \text{average demand for product } p \text{ in market } i \text{ (units/day)},

\rho_{ilp} = \text{correlation between average demands for product } p \text{ in markets } i \text{ and } l,

La_{fjp} = \text{average replenishment lead time of product } p \text{ from factory } f \text{ to warehouse } j \text{ (days)},

\sigma_{Db_{ip}} = \text{standard deviation of demand for product } p \text{ from market } i \text{ (units/day)},

\sigma_{La_{fjp}} = \text{standard deviation of replenishment lead time of product } p \text{ from factory } f \text{ to warehouse } j \text{ (days)},

ka_{jp} = \text{service level at warehouse } j \text{ for product } p \text{ (safety factor reflecting level of protection against stock-outs)},

T_{ilp} = \text{unit cost of transport related to the distribution of product } p \text{ between market } I \text{ and warehouse } j \text{ ($/unit)},

Tr_{fjp} = \text{unit cost of transport related to the supply of product } p \text{ from factory } f \text{ to warehouse } j \text{ ($/unit)},

T_{\text{fact}_{fp}} = \text{unit cost of transport related to the direct distribution of product } p \text{ from factory } f \text{ to market } I \text{ ($/unit)},

\text{CapFact}_{fp} = \text{factory } f \text{'s production capacity related to product } p \text{ (units)},

\text{CProd}_{fp} = \text{product } p \text{'s unit cost of production at factory } f \text{ ($/unit)},

\text{Price}_{p} = \text{product } p \text{'s unit selling price ($/unit)},

I_{\text{Fact}_{\text{CD}}_{fj}} = \text{ICMS tax rate on the flow of goods from factory } f \text{ to warehouse } j \text{ (%),}

I_{\text{Fact}_{\text{Mark}}_{fi}} = \text{ICMS tax rate on the flow of goods from factory } f \text{ to market } i \text{ (%),}

I_{\text{CD}_{\text{Mark}}_{ij}} = \text{ICMS tax rate on the flow of goods from warehouse } j \text{ to market } i \text{ (%),}

\text{CredFact}_{f} = \text{ICMS credits accumulated by factory } f \text{ ($).}

Variables:

W_{ijp} = \text{proportion of the average demand for product } p \text{ from market } i \text{ served by warehouse } j,

W_{\text{fact}_{fp}} = \text{proportion of the average demand for product } p \text{ from market } i \text{ served directly by factory } f,

Y_{fjp} = \text{binary variable that indicates whether factory } f \text{ supplies product } p \text{ to warehouse } j.

\begin{align*}
Y_{fjp} &= \begin{cases} 
1 & \text{if factory supplies product } p \text{ to warehouse } j \\
0 & \text{if it does not.}
\end{cases}
\end{align*}

Objective function:

\text{Minimize } TC_{\text{Network}} = TC_{\text{Replen}} + TC_{\text{Dist}} + TC_{\text{CS/OP}} + TC_{SS} + TC_{\text{ICMS}}. \quad (5)

Subject to the following restrictions:

\begin{align*}
\sum_{j=1}^{m} W_{ijp} + \sum_{f=1}^{k} W_{\text{fact}_{fp}} &= 1 \quad \forall i, p, \quad (6) \\
\sum_{j=1}^{m} \sum_{i=1}^{n} Y_{fjp} W_{ijp} Db_{ip} + \sum_{i=1}^{n} W_{\text{fact}_{fp}} Db_{ip} &\leq \text{CapFact}_{fp} \quad \forall f, p, \quad (7)
\end{align*}
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\[
\sum_{f=1}^{k} Y_{fp} = 1 \quad \forall j, p, \quad (8)
\]

\[
TC_{ICMS} \geq 0, \quad (9)
\]

\[
0 \leq W_{ij} \leq 1, \quad (10)
\]

\[
0 \leq W_{fact_{ij}} \leq 1, \quad (11)
\]

\[
Y_{fp} \in \{0, 1\}, \quad \forall f, j, p. \quad (12)
\]

Where:

\[
TC_{Replen} = \sum_{p=1}^{r} \sum_{j=1}^{m} \sum_{f=1}^{k} \sum_{i=1}^{n} Y_{fp} T_{fp} W_{ijp} D_{ip}, \quad (13)
\]

\[
TC_{Distfact} = \sum_{p=1}^{r} \sum_{f=1}^{k} \sum_{i=1}^{n} T_{fact_{fp}} W_{fact_{fp}} D_{ip}, \quad (14)
\]

\[
TC_{DistCD} = \sum_{p=1}^{r} \sum_{j=1}^{m} \sum_{f=1}^{k} \sum_{i=1}^{n} T_{ijp} W_{ijp} D_{ip}, \quad (15)
\]

\[
TC_{CS/OP} = \sum_{p=1}^{r} \sum_{f=1}^{k} \sum_{i=1}^{n} Y_{fp} \sqrt{2A_{af} C_{af} \sum_{i=1}^{n} W_{ijp} D_{ip}}, \quad (16)
\]

\[
TC_{SS} = \sum_{p=1}^{r} \sum_{j=1}^{m} \sum_{f=1}^{k} Y_{fp} k_{af} C_{af}
\]

\[
\times \sqrt{\left(\sum_{i=1}^{n} W_{ijp}^{2} \sigma_{D_{ip}}^{2} + 2 \sum_{i=1}^{n-1} \sum_{l=1}^{i} W_{ijp} W_{ilp} \rho_{ilp} \sigma_{D_{ip}} \sigma_{D_{lp}} \right) + \sigma_{L_{af}}^{2} \left(\sum_{i=1}^{n} W_{ijp} D_{ip}\right)^{2}}. \quad (17)
\]

\[
TC_{ICMS} = \text{Debits} - \text{Credits} \quad (18)
\]

\[
\text{Debits} = \sum_{p=1}^{r} \sum_{m} \sum_{f=1}^{k} \sum_{i=1}^{n} Y_{fp} W_{fact_{fp}} D_{ip} \text{CProd}_{fp} I_{FACT\_Mark_{fi}}
\]

\[
+ \sum_{p=1}^{r} \sum_{f=1}^{k} \sum_{i=1}^{n} Y_{fp} W_{ijp} D_{ip} \text{CProd}_{fp} I_{CD\_Mark_{ij}}. \quad (19)
\]

\[
\text{Credits} = \sum_{f=1}^{k} \text{CredFact}_{f} + \sum_{p=1}^{r} \sum_{j=1}^{m} \sum_{f=1}^{k} \sum_{i=1}^{n} Y_{fp} W_{ijp} D_{ip} \text{CProd}_{fp} I_{FACT\_CD_{fj}}. \quad (20)
\]

Restriction (6) ensures that network demand is fully met by the factories and/or warehouses. Restriction (7) ensures that each factory’s production capacity limit is observed, while restriction (8) establishes that each warehouse can only be supplied by a single factory. This means that order splitting, whereby a warehouse manages its replenishment independently and splits its orders among multiple suppliers (Evers 1999), is not allowed. This restriction is in line with Thomas and Tyworth (2006). These three restrictions are jointly responsible for ensuring the
network’s material flow balance. Restriction (9) ensures that the network’s ICMS tax balance is positive. This means that no credits can be accumulated for recovery at a future date, so that capital is not tied up. Finally, the limits of the decision variables are defined, whether continuous ($W_{ijr}$, $W_{fact_{ij}}$) or binary ($Y_{ijp}$).

The modelling does not consider costs related to the opening of facilities (e.g. factories or warehouses), a condition that is somewhat restrictive yet adherent to the reality of the logistics network reassessment case study that will be presented later in this study.

The proposed model can be classified as a Mixed Integer Nonlinear Programming Problem (MINLP). Compared to Mixed Integer Programming (MIP) and to Nonlinear Programming (NLP) problems, the resolution of this model is much more complex and computationally expensive (Grossmann 2002).

4.1. Computational tools and case study background

Our MINLP was developed using the Advanced Integrated Multidimensional Modeling Software 3.11 platform, which is appropriate for modelling complex optimisation problems (Ferreira Filho and Ignacio 2004). In order to resolve MINLP problems, the AOA solver was used. This solver uses two other solvers – CPLEX 12.3 and CONOPT 3.14G – for the resolution of MIP and NLP models, respectively (Ferreira Filho and Ignacio 2004).

The model was applied in the Nova Braskem case because after the two Brazilian chemical companies Braskem and Quattor’s underwent a merger to form the new company, management considered it important to conduct a thorough reassessment of the logistics network that resulted from the merger. This merger involved 3 factories, 12 warehouses and about 20 markets on consumer locations to be serviced.

Additionally, in the preceding due diligence, Braskem (2011a) predicted that the merger could lead to the capture of approximately US$200M in synergies in the industrial and logistics areas in 2011 alone. Furthermore, the company also assumed that, after the merger, it would be possible to substantially improve the sales and operations planning (S&OP) process for the various resulting industrial units by being better able to define production mixes for each plant, for example. In the case of the logistics footprint, the gains were expected to come mainly from transportation, because of the more efficient planning of domestic and international sales, distribution and storage.

Thus, given the design of the logistics network and the considerable potential in terms of the financial returns associated with the creation of Nova Braskem, the aim of the model application is to determine what would be the optimal logistics network for the company (in terms of its design and operation) as well as to more objectively quantify the potential gains generated by the reviewed logistics network.

4.2. Determination of the parameters for the application of the model to the Nova Braskem case

Data selection and collection are crucial to the development of a logistics network planning study as they provide the inputs for the mathematical model to be used in support of the effort to achieve an optimal solution to the problem (Davariz 2006). The objective of this section is to explain the rationale behind the choice of the model’s parameters, and to analyse the elements that are most important in the reassessment of a logistics network.

In order to apply the developed model to Nova Braskem, our analyses considered the following aspects of the logistics network created by combining Braskem’s and Quattor’s previous networks (Table 6).

Below, some aspects of the model application are established.
Table 6. Factors that influence the definition of Braskem’s logistics network.

| Products | The products considered were polyethylene (2) and polypropylene (P2), given that the greatest synergies derived from the integrated operation were verified in the case of these products manufactured by both companies, who practically divide the Brazilian market between them. |
| Demand  | Given the atomisation of the company’s customer network, it was decided to aggregate its markets by state. States’ demand was fully allocated to their respective capitals, constituting a total of 27 demand units. |
| Prices  | The products’ (P1 and P2) selling prices in US$/ton (during the period analysed) were obtained from the specialised portal QuiMax Prices, and based on each product’s average price during the fourth quarter of 2010. This constitutes a reasonable approach given that, according to Braskem (2011a), the prices paid by its Basic Input Units and Petrobras for ethylene and propylene are based on international prices. |
| Transportation | The study considered road transportation – undertaken by a standard vehicle such as a 30-ton capacity truck. This assumption was justified by the fact that the road transportation mode accounted for approximately 83% of the resins (P1, P2 and PVC) transported by Braskem. The Geographical Information System at the Guia Quatro Rodas website was used to obtain the distances covered. |
| Inventory costs | Unit inventory maintenance costs were determined separately for each company, as Braskem and Quattor have different unit costs. Given the lack of data on safety stock costs the study chose the value used by Montebeller Jr. (2009), implying that there is an 85% probability that there will be no product shortage during replenishment lead-time. |
| Customer service | The customer service provided by the logistics network should assure that all demand from consumer markets is met. It should also guarantee the safety factor assumed for safety stock kept in warehouses, accommodating demand and/or lead-time variabilities. |

Table 7. Estimate of the demand for petrochemical products from each factory/plant.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>State</th>
<th>Company</th>
<th>Product</th>
<th>CapFact&lt;sub&gt;fp&lt;/sub&gt; (tons/day)</th>
<th>Quarterly production (tons/thous)</th>
<th>Demand for basic petrochemicals (tons/thous)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camaçari BA</td>
<td>Braskem</td>
<td>PE</td>
<td>2.139</td>
<td>2.139</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>Paulínia SP</td>
<td>Braskem</td>
<td>PP</td>
<td>972</td>
<td>972</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>Triunfo RS</td>
<td>Braskem</td>
<td>PE</td>
<td>3.403</td>
<td>3.403</td>
<td>247</td>
<td></td>
</tr>
<tr>
<td>Triunfo RS</td>
<td>Braskem</td>
<td>PP</td>
<td>2.056</td>
<td>2.056</td>
<td>177</td>
<td></td>
</tr>
<tr>
<td>Camaçari BA</td>
<td>Quattor</td>
<td>PP</td>
<td>319</td>
<td>319</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Cubatão SP</td>
<td>Quattor</td>
<td>PE</td>
<td>389</td>
<td>389</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Duque de Caxias RJ</td>
<td>Quattor</td>
<td>PE</td>
<td>1.500</td>
<td>1.500</td>
<td>209</td>
<td></td>
</tr>
<tr>
<td>Duque de Caxias RJ</td>
<td>Quattor</td>
<td>PP</td>
<td>861</td>
<td>861</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>Mauá SP</td>
<td>Quattor</td>
<td>PP</td>
<td>1.250</td>
<td>1.250</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>Santo André SP</td>
<td>Quattor</td>
<td>PE</td>
<td>1.000</td>
<td>1.000</td>
<td>139</td>
<td></td>
</tr>
</tbody>
</table>

Source: Adapted from Braskem (2011b).

First, after determining the location (state) of each network node, the study extracted the parameters related to the ICMS rates charged for the circulation of goods between them directly from Table 1: I_FACT_CD<sub>j</sub>, I_FACT_MARK<sub>i</sub> e I_CD_MARK<sub>ij</sub>.

The estimation of the parameter related to the ICMS credit that has been accumulated by the network’s plants (CredFact<sub>j</sub>) – resulting from their input purchase/receiving operations – did not consider the accumulation of debits or credits prior to the analysed period (fourth quarter of 2010).

Production figures (about the production of the Polyethylene (P1) and Polypropylene (P2) products) were obtained for each company for the quarter under study, and were then divided in proportion to each plant’s capacity (CapFact<sub>fp</sub>). In addition, an estimation (based on revenue data published by Braskem 2011b) was made of basic petrochemical needs (i.e. ethylene and propylene) for the respective productions of P1 and P2 during the period. Table 7 summarises this.
The study considered only these two production inputs (i.e. ethylene and propylene) as they represent the most relevant costs in the P1 and P2 production processes. In the case of Braskem, for example, these products account for approximately 90% of its plants’ variable costs (Braskem 2011a).

The next step was to map out the sources of basic petrochemical supplies. In the case of both Braskem and Quattor, ethylene is supplied directly by adjoining first-generation plants (Braskem 2011a), thereby constituting an intra-state flow of goods.

Once we developed the model, decided about the computational tools, defined parameters consistent with the study case, and mapped out the sources of supply, we then proceeded to analyse the results of the application of our model and perform sensitivity analysis. These steps are described below.

5. Analysis and discussion

Analyses performed here followed the steps commonly used when analysing logistics network problems; that is, we observed the incremental rationale of the different cost components (Wanke, Montebeller Jr., and Tardelli 2010). Basically, we considered the possibility of closing/opening facilities and the presence/absence of inventory holding cost in order to assess their impacts on total costs and on the logistics network configuration.

5.1. Analysis

In order to verify the potential savings of Nova Braskem’s integrated operation, we initially estimated Braskem’s and Quattor’s previous logistic network costs.

Our study assumed that all warehouse facilities mapped were in use. We found that the optimised solution did not indicate the closure of any warehouse facility, thus showing that the previous networks had not taken full advantage of the benefits resulting from the model’s application.

The flows related to the optimisation of Braskem, Quattor and the integrated operation (Nova Braskem) assume that all warehouses are in use and are presented in Figures 1–3. They show that direct distribution prevails over echeloned distribution, given that warehouses are used mainly in the case of markets with lower levels of demand. Table 8 confirms this for the reference scenario where no inventory costs are considered and all facilities remain opened.

Figure 1. Optimised flows of Braskem’s logistics network.
In the two scenarios studied, the use of direct distribution prevails. In terms of percentage, direct distribution accounts for approximately 94% of the demand for resins met by the companies. Thus, it is important to ensure reliability in direct delivery from industrial facilities.

When the assumption related to the operation of all warehouses is relaxed, the model tends to suggest direct distribution only without the use of any warehouse; however, this result does not seem to make sense from a business perspective. Thus, the assumption related to this type of distribution option will be further explored in the sensitivity analysis.

In order to quantify the gains obtained from the redesign of the logistics network, an analysis of the objective function’s three main cost components was performed. The first component is inventory holding costs, which show an increase of US$2011 per day. This increase in inventory holding costs occurred due to the slight increase in the percentage of echeloned distribution in the total demand served by the network.

The integrated operation was found to be beneficial in terms of the logistics network tax-related costs. It was precisely in this area that the model’s application in the case study displayed the most significant gains, resulting in savings in ICMS costs of US$190,986 per day. In addition,
transportation logistics costs fell by US$51,297 per day. These savings came from better allocation of consumer markets to facilities in the network.

Finally, analysis was performed of the total cost of the merged operation studied. We found that, given the assumptions, daily savings obtained by applying the proposed model to Nova Braskem’s integrated operation amounted to approximately US$ 240,000 per day, or approximately 25–40% of the total daily costs as predicted by the model (cf. Figure 4), depending on the cross-filling assumption. During the period considered in the study (fourth quarter of 2010), the potential savings amounted to approximately US$21.5M.

There are potential additional gains from the closure of warehouses that are underutilised by the network. The figures we obtained from the study are relatively consistent with Braskem’s (2011a). The company itself estimates annual savings of US$235M in industrial and logistics synergies resulting from the creation of Nova Braskem. Our findings show that, with the redesigned network, savings in transportation costs far exceed those related to the other components of our objective function (tax- and inventory-related).

5.2. Sensitivity analyses

In order to better evaluate trade-offs between the performance aspects of our study, this section presents the results of a number of sensitivity analyses performed.

The first sensitivity analysis involves exploring the possibility of direct distribution from the factory. Since the case study suggested that this was the main distribution option to be used in an optimised situation, we decided to limit the value of the variable associated with this assumption ($0 \leq W_{\text{fact}} \leq W_{\text{fact max}}$) and study the behaviour of the objective function’s components. Figure 4 summarises this analysis.

This new restriction forces a greater use of the network’s warehouses, and consequently leads to higher inventory holding costs. We also analysed the existence of a possible trade-off between logistics costs and tax-related costs, as described by Yoshizaki (2002). For certain networks, as transportation costs increase, there is a corresponding reduction in ICMS-related costs. This is due to the ‘product tourism’ induced by the current structure of different ICMS tax rates by state; however, ‘product tourism’ was not suggested in the model optimisation in the case study because the increase in transportation and inventory costs exceeded the potential reduction in...
tax-related costs. This may be caused by the nature of the particular product studied in our case. Petrochemical commodities are bulky products with relative low value density as compared to electronics or pharmaceuticals, for example. With products that have more value density, it is likely that the financial advantages of product tourism in a tax structure such as that of the Brazilian ICMS will become more attractive to companies.

The second sensitivity analysis performed aims to understand how inventory holding cost considerations influence the solutions found in the merged network. We first applied the optimisation model to Nova Braskem logistics network, but without considering inventory holding costs. This analysis, presented in Table 9, showed a significant increase in the percentage of echeloned distribution (via warehouses) as suggested by the optimised solution, as it is now legal for facilities to be closed.

Comparing the merged operations transportation cost/ICMS relation determined in Section 4.1 with the findings of the sensitivity analysis, the study revealed the same trade-off between logistics and ICMS: higher transportation costs are offset by lower tax-related costs. In this case, the lack of inventory holding cost effects illustrates this trade-off quite clearly. In the case analysis, ICMS-related costs declined from US$64,883 in the reference scenario to only US$27,888 in the sensitivity analysis, a reduction of 43%. The transportation cost, on the other hand, rose from US$536,031 in the reference scenario to US$549,205 in the sensitivity analysis, representing an increase of 2.5%, as shown in Figure 5.

One of the aspects revealed by the sensitivity analysis is particularly noteworthy. The participation of three warehouses used by the logistics network – Contagem (state of MG), Três Corações (state of MG) and Joinville (state of SC) – constitutes a case in which the network was designed with tax avoidance in mind.

The following illustration presents the flows that support this statement. In Figure 6(a), one can observe the ‘product tourism’ from the state of São Paulo to the state of Rio de Janeiro via the warehouses of Minas Gerais state. However, this ‘tourism’ is even more visible in Figure 6(b),
where the goods produced in the state of Rio Grande do Sul travel to the state of Santa Catarina and then return to their state of origin.

The conclusion is that, when inventory-related costs are considered, it becomes clear that use of the logistics network’s warehouses is prohibitively expensive, and thus direct distribution is favoured.

The aim of the final sensitivity analysis was to examine the impact of tax aspects on the logistics network’s configuration. Thus, the optimisation of the logistics network was performed without including the tax component in the objective function. Excluding taxes from our consideration causes transportation costs to drop, given that there is no incentive to use echeloned distribution. Therefore, the results should be compared with those obtained from the optimisation of the reference scenario, without the mandatory operation of any warehouse. The reference scenario’s transportation costs amounted to US$534,242 as compared to US$297,105 in the sensitivity analysis, or 55.6% of the former transportation costs. This difference is solely due to the consideration of ICMS. Once again, this shows that taxes have a considerable impact on the logistics network costs and design.

6. Conclusions and implications

This study investigated logistics network planning. We proposed a mathematical programming model that considered the logistics costs related to transportation, inventory maintenance and tax-related aspects in Brazil. One distinguishing feature of this study was its consideration of a nonlinear treatment of inventory costs. By considering these components in the objective function, the model makes a theoretical contribution.

The practical application of the model in a real case study helped validate the study. Upon performing scenario analysis, we were able to quantify the potential gains resulting from the redesign of the Nova Braskem logistics network.

In the case study, we found that the logistics costs of transportation far exceeded those related to the objective function’s other components (i.e. taxes and inventory), thus explaining why direct distribution prevailed over echeloned distribution via warehouses. The use of the first mode enables
firms to avoid incurring additional transportation and inventory costs, thus minimising inventory holding costs in the logistics network. This is possibly caused by the nature of the product studied.

Our results also provide valuable insights for decision-makers in the analysed industry and underscore the importance of logistics network planning for business. Moreover, the gains observed demonstrated the inherent value of periodically reassessing the design/operation of logistics networks. Even though transportation costs prevailed over other cost categories, the tax-related aspects (ICMS) showed the most potential in terms of financial advantages. Thus, it was possible to demonstrate its importance at least in the Brazilian business context and in other contexts that work under similar conditions. Moreover, given the nature of the case study, it is clear that logistics network planning is an important tool for supporting the quest for synergies in corporate M&A operations.

Of particular importance is the effect that different VAT-type rates in different states of a country or region can have in the design and management of logistics networks. We have not found any other study in literature that evidences that effect and we consider that this is a relevant contribution of this research.

One limitation of the study is that its consideration of warehouse inventory-related costs places echeloned distribution at a disadvantage in relation to direct distribution. As petrochemicals are bulky and expensive to transport and not very dense in value, this effect was particularly sensitive in our analysis. We hypothesise that a similar study with less bulk and, more value-dense products (e.g. electronics and pharmaceuticals) could show very different results in relation to this aspect.

We also did not consider the possibility of storing inventory in factories, and this constitutes a limitation of our study that should be further explored in future studies. Another limitation of our study concerns the fact that we worked with the Brazilian tax structure. Any generalisation of our specific results should be done very carefully by checking whether the other cases in question actually work under the same general conditions as those found in our case.

Furthermore, our assumption of deterministic (as opposed to stochastic) flows to consumer markets constitutes a limitation that may have a significant impact on the level of service provided by the logistics network. Thus, it may be interesting to consider some randomness of demand in future studies. On a different note, future studies could also consider various modes of transportation and their effect on network design optimisation. Finally, in order to examine/confirm and possibly generalise the findings of our study, the model developed could be applied to other cases with results compared and contrasted to ours.

Notes


References


