A multi-commodity two-stage production-distribution system design problem: the impact of different customs systems

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Abstract
This research studies the impact of customs system regime in a logistics network design for an aircraft manufacturer with plants in Brazil and China. Changes in the logistics costs provided by two tax regimes are evaluated. A location and transshipment model with multi-product is applied to optimize the logistics costs and to determine where goods are consolidated. The results show that the tax regime significantly affects logistics costs and goods consolidation. Thus, it is crucial to understand the referred tax regimes, to avoid severe logistics network system sub-optimization.

Keywords: Location; Transshipment; Customs Systems, Aircraft Industry.

Introduction
The aim is to analyze the impact of customs system regime in a logistics network design for a manufacturer of commercial and military aircraft with plants installed in Brazil and abroad and with international activities in Harbin (China). The decentralization of the industrial operations of the company makes its supply complex, especially with the startup of new units abroad (Harbin, China), which receive material from the United States, Europe and Brazil.

This analysis considers inventory costs, transportation and distribution, and fixed costs, allowing quantifying the influence of regimes customs in logistics costs of a supply chain and its effects on the logistics network.

Air transportation is an industry highly sensitive to cyclical fluctuations in the economy and requires intensive use of capital and manpower for procurement, operation and maintenance of aircraft, having very long logistics cycles. It also requires economies of scale and responses to the growth or retraction of the market inside a scenario with high
competition between airlines. The need for rapid response conflicts with the cycles of new aircrafts deliveries, which are usually long.

This characteristic requires an anticipation of demand and hence of purchases by airlines. Thus, the air transport market demands from aircraft manufacturers a flexible supply chain to absorb the fluctuations of this market, besides a constant exchange of information with partners and suppliers in order to minimize negative impacts and / or maximize the return on sales. The flexibility of production lines to absorb delays and acceleration of orders and to postpone the setting of specific and different characteristics of the aircraft, assembled according to the customer, are also requirements for the supply chain. These aspects, together with the product design, can be treated as competitive differential of aircraft manufacturers.

The aircraft industry in Brazil has challenges, especially in the logistics for purchasing and carrying materials from suppliers to the plants. Its suppliers and customers are located in the United States, Europe and Japan. This situation has become more complex with the installation of plants in China.

The problem consists in minimizing total logistics costs through a mixed integer programming, identifying which products go directly from suppliers to the consumer unit and which products undergo a transshipment step in a consolidation center. The problem lies in finding the optimum location of distribution centers from a set of candidate sites, so that customer demand is met, and the total cost of transport and storage is minimized. This problem is classified as a two-stage production-distribution system design problem (TSPDSDP) with multi-commodity.
Literature review

Melo et al (2009) state that plant location decisions have a critical role in the strategic design of supply chains and characterize the facilities location problem as a set of customers spacially distributed which are served by a set of facilities. Daskin (2008) presents a taxonomy for the location problem subdividing the problem into analytical, continuous, network and discrete models.

Two-stage production-distribution system design problem (TSPDSDP) and its extensions

According to Matisziw (2005), in the transshipment problem (TSP), instead of transporting the products directly from various sources to various destinations as occurred with the classical transportation problem, there are some intermediate transshipments points (facilities) which can connect these paths in order to reduce logistics costs. For Keskin and Üster (2007), the TSP considers three echelons in the supply chain where the transportation process occurs in two stages: transportation from suppliers points to transshipment points and transportation from transshipment points to demand points. The goal of the TSP is to determine the flow of goods from a set of origins to a set of destinations via a set of intermediate facilities aiming to minimize the total transportation cost involved in the system.

Another important logistics problem that has been widely studied in the literature in the last decades is the facility location problem (FLP). The term “facility” includes factories, depots, air and maritime ports, terminals, etc. The objective of the Facility Location Problem is to determine the number of facility locations, select the optimal locations among the possible candidates for installing and improving facilities, and the optimal assignments of customers to facilities aiming to satisfy the customers demand.
with the least cost. As occurred in the classical transportation problem, the FLP considers single-stage models limited to two echelons in the supply chain. If facilities have capacity constraints, the problem is called capacitated facility location problem (CFLP). Otherwise, the problem can also be called uncapacitated facility location problem (UFLP).

The two-stage capacitated facility location problem (TSCFLP) considers three echelons in the supply chain. According to Klose and Drexl (2005), the TSCFLP is an extension of the (one-level) capacitated facility location problem (CFLP) if the flow of products from the first to the second echelon is an additional decision variable. For Keskin and Üster (2007), the TSCFLP is also an extension of the transshipment problem where the locations of transshipment points are to be decided. The problem aims to locate $p$ transshipment points and determines shipment designs from suppliers to customers through these points. In the first stage, the product is transported from suppliers to facilities (transshipment points) the locations of which are to be determined. In the second stage, the customer demands are satisfied from these facilities. The objective is to minimize the variable cost of delivery and the fixed operating cost (ELHEDHLI; GOFFIN, 2005). For Keskin and Üster (2007), this problem can also be seen as an extension of the $p$-median problem. In the classical $p$-median problem, the fixed location costs and capacity constraints of the possible facilities are not considered, and the number of facilities is limited. The TSCFLP can also be considered in the literature as a two-stage production-distribution system design problem (TSPDSDP) which, according to Keskin and Üster (2007), involves the determination of the best configuration, regarding location and size of the plants and distribution centers, their technology content, and product supply and transportation decisions. When there are more than 3 echelons in the supply chain, the problem is called multi-stage capacitated
facility location problem (MSCFLP) or multi-stage production-distribution system design problem (MSPDSDP).

Although there is are several studies in the literature considering single-stage facility location problems, researches on two-stage or multi-stage location problems are limited. The most important papers related to the problem studied will be described below. Firstly, works based on multi-commodity are described. One of the first papers in the area is Geoffrion and Graves (1974) who proposed benders decomposition to solve the multi-commodity two-stage production-distribution system design problem. Hindi and Basta (1994) and Hindi et al. (2006) solved the production-distribution problem by a branch-and-bound algorithm. Pirkul and Jayaraman (1996, 1998) proposed a heuristic based on the Lagrangean relaxation of the model to solve the TSPDSDP with multi-commodity. Keskin and Üster (2007) proposed a scatter search algorithm with hybrid improvements including local search and path-relinking to solve a TSPDSDP in which a fixed number of intermediate facilities points are to be located between the plants and customer locations.

_Brazilian customs system regimes_

_Drawback regime_

The Drawback is an incentive to exportation and includes the suspension, exemption or refund of importation taxes of raw materials used in the manufacturing of the exported product (PORTUGAL, 2003). Under the program, authorized participants may import raw materials, semi finished goods, parts and components and packaging materials to Brazil. The goods are to be further manufactured for export. These taxes include:

- **II:** Import duty, Ad-valorem or Specific.
- **IPI:** Tax on industrialized products.
- ICMS: Goods and services tax.
- AFRMM: Tax on freight moved on foreign flag vessels.

**RECOF custom Regime**

In RECOF, the production components are admitted in the country or acquired in the local market with tributary suspension. If the production target is exportation, the company is exempted from the taxes that have been suspended. Another benefit of the regime is that the company can sell imported goods with no industrialization to the external market, provided that the minimum industrialization volume defined by RECOF regulations is met (SOFTWAY, 2011). Recof requires an automated system to control import, export and the materials with tributary suspension. This system needs to be certified by the Brazilian Federal Revenue Authority.

**Aeronautical Recof**

There is a specific Recof for the aeronautical industry. It is limited to manufacturing operations for aircraft assembly, equipment and tools used in aeronautics, the transformation, processing and assembly of parts and components used in manufacture and assembly of instruments used in aeronautics. The export of goods under RECOF regime must be made within one year, extendable for another one.

**Comparing the customs regimes**

The advantages of the Recof regime as compared to the Drawback regime are:

- Allows for importing all the components with tax suspension.
- Allows tolerance of losses in the production process.
• Allows for exportation of up to 20% of imported products, without any industrialization.
• Virtually no Customs checks are required for export operations.
• Reduction in the import clearance time due.
• Significant reduction in the company inventory, since the whole clearance process is easier.

The Recof disadvantages in relation to the Drawback are:
• The costs of implementing the regime, requiring large investments in information systems and the adequacy of operations.
• Make available on line information over all materials stored or in process to the Brazilian Federal Revenue Authority.
• In Recof customs, 100% of the materials are inspected by an automated system, while the Drawback regime uses sampling inspection.

Problem definition and model

Problem definition

The study applies to the materials sent to supply the production line located in Harbin (northern China) which have minimum lot restrictions, due a minimum amount for purchase or restriction of packing. These materials are purchased from suppliers located in the United States and Europe and to supply the production line in Harbin, can be sent directly to the plant or undergo a transhipment in Brazil, Miami, Los Angeles or Paris. Due to the characteristic of minimum lot sizing, it must be considered the trade off between freight plus the financial cost of maintaining these stocks in the consumer unit versus supply this unit with the exact amount of their need from another location, where
there are additional costs of shipping, handling and fixed costs for installation and operation of a transshipment center (consolidation terminal). The consolidation terminals have restrictions of maximum and minimum capacity. The maintenance cost of inventories is due to increased inventory levels to supply the China unit. The Sao Jose dos Campos plant is already buying the minimum lot size to meet the current demand. If the consolidation of the material does not occur in this unit, another minimum lot must be purchased, causing increase in inventories at the plant of destination or any other consolidation terminal. Figure 1 shows the behavior of stocks in each unit, allowing to conclude that the financial cost is the difference in the average cost of capital in each situation.

![Inventory behavior](image)

**Fig 1:** Inventory behavior.

The problem is analyzed using scenarios, comparing customs system regimes and transportation modals. Under the aspect of taxation, the analysis is the change of logistics costs through the implementation of a new customs system regime, called Aeronautical Recof, replacing the current Drawback regime. Regarding the mode of transport, both the air and the maritime modals were considered to transport the materials from the manufacturer to a transshipment unit or directly to the plant of final assembly.

Information about the problem can be summarized:
Planning horizon: the production of 100 aircraft in Harbin;

Origin: the materials are produced in the United States and in Europe;

Local candidates: the candidate sites for the installation of a consolidation terminal (distribution center) are: Sao Jose dos Campos, Los Angeles, Miami and Paris;

Destination: All products are intended for the production line located in Harbin.

The goal is to find the number, size and locations of warehouses in a logistics network that will minimize the fixed and variable costs, subject to the following conditions:

- Demand for all products must be satisfied.
- A minimal processing of a warehouse must be reached before it is opened.
- The processing of each warehouse can not exceed its capacity.
- For each product, the supply capacity cannot be exceeded.

In this problem, each customer could be assigned to more than one facility (multi-sourcing). Besides, differently from most papers found in the literature, we consider the alternative of making direct shipments from suppliers to customers without transshipment points. Figure 2 depicts the local flows and the destination of the materials.
The model

The problem is modeled by mixed integer programming and is based on the work of Hindi and Basta (1994) and Keskin and Üster (2007), with the following indexes:

Suppliers $i \in I$

The suppliers are the United States and Europe.

Consolidation terminal $j \in J$

Candidate sites to open or not a pole consolidator. These sites are:

- São José dos Campos (SJK - Brasil) – operation by the company, the maximum capacity constraint = 4,000 kg;
- Los Angeles (LAX - U.S. West Coast) - operation by logistic partner (3PL), the minimum capacity constraint = 1,000 kg;
- Miami (MIA - U.S. East Coast) - operation by logistic partner (3PL), the minimum capacity constraint = 1,000 kg;
- Paris (CDG - Europe) – operation by logistic partner (3PL), the minimum capacity constraint = 1,000 kg;
- Harbin (HRB – China) – operation by the company. The cost of transferring from this terminal to the final destination is zero.

Plants $k \in K$

Final destination of products, in this case Harbin (China).

Products $p \in P$

The products can be consolidated or not. There are 256 products that have a minimum lot of acquisition that exceeds the economic lot of purchase. The inventory model is reactive, because the purchase of new materials occurs in the period immediately after
the quantity stored reaches the order point. Due to a trade issue, there is only one vendor per product, although the model is able to consider more than one supplier.

The parameters of the mixed integer programming are listed below.

\( Q_j \) maximum capacity of consolidation terminal \( j \) in kg/cycle.

\( q_j \) minimum quantity to open a consolidation terminal \( j \) in kg/cycle.

\( f_j \) fixed cost of locating a consolidation terminal at \( j \), in US$/cycle.

\( D_{pk} \) demand of product \( p \) at plant \( k \) in kg/cycle.

\( S_{ip} \) capacity of supplier \( i \) to produce the product \( p \) in kg/cycle.

\( g_{pj} \) transshipment cost per unit of commodity \( p \) at consolidation terminal \( j \), in US$/kg.

\( c_{ pij} \) unit transportation cost of product \( p \) from supplier \( i \) to consolidation terminal \( j \), in US$/kg.

\( c_{ pjk} \) unit transportation cost of product \( p \) from consolidation terminal \( j \) to plant \( k \), in US$/kg.

\( c_{ pik} \) unit transportation cost of product \( p \) from supplier \( i \) to plant \( k \), in US$/kg.

The decision variables of the model are:

\( x_{ pij} \) quantity (kg) of product \( p \) transferred from supplier \( i \) to consolidation terminal \( j \).

\( y_{ pjk} \) quantity (kg) of product \( p \) transferred from consolidation terminal \( j \) to plant \( k \).

\( z_{ pik} \) quantity (kg) of product \( p \) transferred from supplier \( i \) to plant \( k \).

\( z_j \) binary variable that assumes 1 if the consolidation terminal \( j \) operates and 0 otherwise.

The problem can be formulated as follows:

\[
\begin{align*}
\min & \quad \sum_{p} \sum_{i} \sum_{j} c_{ pij} x_{ pij} + \sum_{p} \sum_{j} \sum_{k} c_{ pjk} y_{ pjk} + \sum_{p} \sum_{i} \sum_{k} c_{ pik} z_{ pik} + \sum_{j} \sum_{p} \sum_{k} g_{pj} y_{ pjk} + \sum_{j} f_j z_j \\
\text{subject to:}
\end{align*}
\]
\[
\sum_{j} y_{pjk} + \sum_{i} z_{pik} = D_{pk}, \quad \forall p, k
\]

\[
\sum_{p} \sum_{i} x_{ pij} \leq Q_j z_j, \quad \forall j
\]

\[
\sum_{p} \sum_{i} x_{ pij} \geq q_j z_j, \quad \forall j
\]

\[
\sum_{j} x_{ pij} + \sum_{k} z_{pik} \leq S_p, \quad \forall i, p
\]

\[
\sum_{i} x_{ pij} = \sum_{k} y_{pjk}, \quad \forall p, j
\]

\[
x_{ pij}, y_{pjk}, z_{pik} \geq 0, \quad \forall p, i, j, k
\]

\[
z_j \in \{0,1\}, \quad \forall z
\]

In the objective function, the first term represents the transportation costs from suppliers to consolidation terminals, the second refers to transportation costs from consolidation terminals to the final customer (Harbin factory), the third represents the transportation costs from suppliers directly to the final customer, and the last two the operational and fixed costs of locating the consolidation terminals, respectively.

Constraint (1) guarantees that the demand for product p at customer k is satisfied.

Constraint (2) is related to the maximum capacity of each consolidation terminal. The minimum quantity for operation of each consolidation terminal is listed by constraint (3). Constraint (4) represents the supply capacity of supplier i for product p. (5) is the flow conservation constraint. Finally, constraints (6) and (7) are non-negativity and integrality constraints.

*Logistics costs considered in the operation*

The logistics costs were divided into three main groups:
• **Transhipment Costs:**
  - Taxes: Import duty (II), Tax on industrialized products (IPI), Goods and services tax (ICMS) and Tax on freight moved on foreign flag vessels (AFRMM).
  - Costs of customs clearance.
  - Costs of material handling in customs area.
  - Costs of receipt, inspection, storage and material handling.
  - Financial costs of maintaining inventories.

• **Transportation Costs:**
  - Air or ship freight.
  - Insurance.
  - Inland Transport.
  - In transit inventory (pipeline).

• **Fixed costs to start a terminal.**

_Drivers and places of occurrence of the costs_

Figure 3 shows the flow of goods in the supply chain and the places of occurrence of the costs.

**Fig 3: Goods flow and costs events.**
Captions:

1 – Materials Origin (Los Angeles, Miami, Paris);
2 – Customs in Brazil (port or airport) on import;
3 – Sao Jose dos Campos plant;
4 – Customs in Brazil (port or airport) on export;
5 – Harbin plant (depot).

Costs related to the product (transhipment and transport) are calculated according to the weight of the product, the product value or simply a function of the item. Table 1 shows, for each cost under consideration, this driver for verification.

Table 1: Costs.

<table>
<thead>
<tr>
<th>Type</th>
<th>Parameter</th>
<th>Where</th>
<th>Cost</th>
<th>Weight</th>
<th>Price</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>3</td>
<td>Tax – Import</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>3</td>
<td>Tax – IPI</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>3</td>
<td>Tax – ICMS</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>2</td>
<td>Tax – AFRMM</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>2</td>
<td>Customs clearance</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>4</td>
<td>Airport tax to export</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>2</td>
<td>Airport tax to import</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>2</td>
<td>Custom duty</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>3</td>
<td>Recept goods, Warehousing and Shipment</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>$c_{pij}$</td>
<td>1 – 2</td>
<td>Air freight</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>$c_{pij}$</td>
<td>4 – 5</td>
<td>Inland insurance</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>$c_{pij}$</td>
<td>1 – 2</td>
<td>Ship freight</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>$c_{pij}$</td>
<td>1 – 5</td>
<td>International insurance</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>$c_{pij}$</td>
<td>4 – 5</td>
<td>In transit inventory</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transhipment</td>
<td>$g_{pj}$</td>
<td>1</td>
<td>Inventory keeping</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Solution and analysis of the results

The software GAMS (General Algebraic Modelling System) was applied to solve the problem of mixed integer programming using the solvers CPLEX (ILOG) and OSL (IBM). In the validation process these two solvers were tested, using all materials (256) on two occasions, with absolute error equal to 0 (zero) and also with a relative error equal to 0.000001. The results showed deviations when the absolute error was established for the solver OSL. It was decided not to use this situation for this solver and to use only the relative error.

The following scenarios were considered for study because they represent the possibilities of the modes of transportation and tax regime. Table 2 summarizes the scenarios used.

Table 2: Scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Taxation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>Direct supply to Harbin</td>
<td></td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Air modal</td>
<td>Recof</td>
</tr>
<tr>
<td>Scenario 3</td>
<td></td>
<td>Drawback</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>Air and maritime modal</td>
<td>Recof</td>
</tr>
<tr>
<td>Scenario 5</td>
<td></td>
<td>Drawback</td>
</tr>
</tbody>
</table>

- Scenario 1 – Direct Supply: this scenario was the initial logistics proposition, considering all materials going directly to the Harbin plant.
- Scenario 2 and 3 – air modal.
- Scenario 4 and 5 – maritime mode for the transportation from the supplier to consolidation terminal and the pole to Harbin by the air mode.

Figure 4 presents the costs in each of the evaluated scenarios:
Figure 4: Costs in each scenarios.

**Implementation of the model**

Operation of the Harbin plant began in 2004 with an initial proposal for assembling 100 aircraft by mid of 2011. In 2006, production reached its nominal cadence. The Recof regime effectively began in 2008; however, the consolidation of material was considered from the start of operations according to the Recof regimen. In the period 2006 to 2008, despite the Drawback regime operation, the consolidation of Recof regime was followed, mainly due to non-amendment of contracts with international suppliers.

**Conclusions**

Aiming to verify the possible changes in the consolidation of materials an analysis of the impact of customs regimes in international logistics was developed. This analysis used a mixed integer programming model that optimized the cost of transport, transhipment and financial materials that have lot size over the economics purchase.
It was found that the lot size and product cost directly affect the consolidation of materials. The larger is the lot size, the smaller is the impact of transshipment in the total cost. Products with high value and big purchase lots took the transshipment, while low-value products and small lots did not perform the transshipment.

The results obtained from these scenarios showed that the change in customs regime affects the logistics of materials consolidation, which was also affected by the lot sizing and the product cost, there being no correlation between the consolidated materials in these two situations. This occurs due to the taxation criteria that vary according to the Brazilian fiscal classification of the material. In the Aeronautical Recof regime, the amount of materials with transshipment in Brazil is higher than the amount in the Drawback regime.

These changes in customs regime occur due to government efforts to facilitate exports, and also to facilitate the inspection carried through by the Federal Authority. Changes in the customs procedure that may occur during a process operation may jeopardize the entire logistics process and lead to profound changes in logistics for supply or distribution.

In addition, to provide earnings by reducing logistics costs, the customs regime of Aeronautical Recof also promotes advantages in the competitive strategy, by reducing the logistics cycle and the lead times of supply, providing greater flexibility in production lines and hence a greater capacity for meeting the customers requirements.

References


