Supply Chain & Transports Optimization

Volkswagen Autoeuropa Case Study

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Abstract

The advanced internationalization and evolution of markets and production processes continuously adds to the complexity of supply chains, along with an increased pressure to improve the sustainability of processes and optimize their efficiency. In a world that is increasingly demanding to have the right product at the right time and place, transportation is one of the most fundamental activities within a supply chain. Given this importance, there is a continuous pursuit of optimization opportunities in this area that can contribute to an increased efficiency of the supply chain as a whole.

This work addresses the case study of a car manufacturer, Volkswagen (VW) Autoeuropa (AE), with specific focus on inbound logistics and the challenges the company encompasses when trying to incorporate transportation costs specificities into transportation and replenishment decisions.

In this paper, two approaches are proposed to solve the problem. First, a manual approach is performed in order to provide and assess different frequency transportation scenarios, leading to a tool to support decision-making. Then, a mixed integer linear programming model (MILP) is developed in order to validate and optimize the current transportation scenarios.

Keywords: *supply chain management; transportation decision-making; transportation management; freight modeling; inbound logistics*.

1. Introduction

Worldwide and across industries, supply chains (SC) are continuously forced to perform exceptionally better by the day, customers demand higher service levels and competition tightens. Within the supply chain, several players need to be taken account. Focused on outcomes, a competitive supply chain capability not only assures the on-time delivery of component material, but also the execution of inbound supply to ensure the shipment of quality finished goods at a competitive price while delivering on-target margins for the manufacturers.

Therefore, transportation is an indispensable activity in a supply chain, yet it can account for more than 50% of total logistics costs (Swenseth & Godfrey, 2002), thus becoming obvious why optimizing transportation costs is a priority for companies. Without well-developed transportation systems, logistics could not bring its advantages into full play. Furthermore, transportation impacts other areas of the company, since usually transportation costs are diminished by increasing the quantity being shipped, so the company needs to build up inventory, which also represents costs. More, and within a just-in-time manufacturing context, companies need to have a very efficient and reliable transportation system, since the requirements are notified with a short advance, suppliers need to be ready, otherwise it will be necessary to perform special transports, which are, of course, costly.

The problem addressed in this work concerns Volkswagen Autoeuropa, which is an automotive manufacturing plant of the Volkswagen Group, located in Palmela. The company identified the necessity of optimizing transportation strategies, namely concerning the behavior of transportation rates charged by carriers, since it was identified that some of the rates structure were not linear and had a piecewise structure, with constant values for different weight values. Being so, there was a motivation to study if it could be possible to take advantage of these behavior and try to increase the shipment size and/or decrease the frequency of the shipments, reducing the value per unit and eventually leading to the suppression of some pick-ups, hence saving the cost of some trips to that supplier.

The objective of the present paper is to study, in terms of costs, the current transportation scenarios, and their implications in inventory with the goal of proposing alternative scenarios that lead to an improvement of the overall efficiency.

To do this two approaches were undertaken: first in a more manual manner using MS Office Excel and the second, with a Mixed Integer Linear Programming (MILP) model proposition.

The paper is structured as follows: in Section 2, relevant literature on the design and planning of supply chains, transportation decision making and transportation network design is presented. In Section 3, a complete problem statement is presented. The manual approach and mathematical model are presented in Section 4. In Section 5 the approaches are applied to different scenarios and the results are compared. A sensitivity analysis is conducted in order to study the influence of the variation of certain parameters. Finally, in section 6 some conclusions are drawn.

2. Literature review

Supply Chain and Supply Chain Management

Today, individual firms no longer compete as independent entities with unique brand names, but rather as integral parts of a network. As such, the ultimate success of a firm will depend on its managerial ability to integrate and coordinate the intricate network of business relationships necessary to deliver products to customers (Lambert & Cooper, 2000).

Different authors present diverse definitions, found in the literature, that intend to explain the Supply Chain concept. In shorter words, Ballou (2004), states that the term supply chain refers to all of those activities associated with the transformation and flow of goods and services, including their attendant information flows, from the sources of raw materials to end users, with the traditional objective of minimizing the total supply chain cost to meet fixed and given demand. However, this should be performed whilst maximizing, simultaneously, the overall value (Chopra & Meindl, 2007).

Supply chains have evolved significantly throughout the years, as the term can be traced back to the 1980s (Coyle et al, 2011). From that point until today, several trends have been gaining importance and influenced the way SC are managed and designed. On one hand, the worldwide economic growth has given rise to a vast consumption of goods, while globalization has led to a large stream of goods all over the world. The production, transportation, storage and consumption of all these goods, however, have created large environmental problems. In the sense of integrating adequate environmental management into supply chains and its activities, the concepts of green logistics and green supply chain management (GSCM) have emerged, with the aim to reduce the environmental externalities of logistics operations. (Green Logistics, 2016). On the other hand, there is a shift in the traditional view of SC towards a network approach meaning that companies must find a way to improve communication and information flow, thereby converting the traditional supply chain into a flexible and real-time supply network. (Ladd, 2004).

Transportation in Supply Chain

Transportation Role and Decisions in Practice

Transportation is one of the most structuring activities of Logistics and it’s responsible for a big share of the logistics costs, around one to two thirds (Ballou, 2006). The goal of making the SC more agile also transfers a big share of the costs to the transportation sector, while trying to decrease costs in inventories and warehouses. With transportation being so essential in a SC, it cannot be managed in an isolated manner, since options about the mode and the type of transportation solutions have a significant impact in the cost structure and in the company’s ability to react to demand, as well as noteworthy repercussions throughout the whole SC. Only a good coordination between each component would bring the benefits to a maximum (Tseng, 2005).

When it comes to transportation decisions there are some key trade-offs to consider:

- *Transportation and inventories -* Transportation time of goods has an increased impact on inventory, whether it is inventory in transit, cycle inventory or safety stock. Thus, transportation decisions should always incorporate the influence it has on stock costs.
- *Time versus space -* Also, frequency is one of the most relevant and impactful characteristics, with great importance in costs. As a matter of fact, a

high supply frequency shows a great response capacity from the supplier, but can translate into higher transportation costs. Space availability in the destination facilities is also one factor that needs to be considered when deciding transportation modes and consequent shipment sizes (Crespo de Carvalho, 2010).

In sum, a trade-off between responsiveness and costs (transportation, inventory, space, among others) must always be evaluated.

When designing a transportation network, initial transportation decisions are seen as strategic, with a broader focus on the overall supply chain transport system and then the decision-making scope becomes increasingly operational in nature, focusing on activities that implement the overall system decisions (Stank & Goldsby, 2000). In general, transportation modelling and network design and decisions face some commonly encountered problems, as mode selection, carrier selection, carrier routing, fleet sizing, and vehicle scheduling and shipment consolidation.

Integrated transportation decision making

The importance of transportation management with a broad concern for the entire SC has been repeatedly stressed, as much as it has been highlighted by the scientific community. In Crainic & Laporte (1997), authors aim to identify the main issues in freight transportation planning and operations, with a classic three decision levels approach (strategic, tactical and operational). Stank & Goldsby (2000), develop a framework for transportation decision making in an integrated SC, since they identified, at the time, the lack of conceptual research regarding the role of corporate transportation function in an integrated SC. Regarding network flows, Kim & Pardalos (1998) consider the fixed charge network flow problem (FCNFP), and propose a new approach for solving the general capacitated (or uncapacitated) FCNFP by adapting an economic viewpoint of the fixed cost. Authors acknowledge that this problem has many practical applications including transportation, network design, communication and production scheduling, and although many exact methods have been developed to solve the FCNFP, their computational requirements increase exponentially with the size of the problem, so heuristic approaches are needed to solve sub optimally large-scale problems, and most solution approaches until that time included branch and bound techniques and vertex ranking procedures.

Modelling and defining transportation costs

Transportation costs can greatly differ dependent of a series of variables. Authors in scientific research have tried to develop different approaches to tackle some of the possible specific differences and price structures.

Guo, Wang & Zhou (2015) consider the transportation problem with uncertain costs and random supplies. Sahin, et al. (2009) develop a model for analyzing total transportation costs, for cargo or passengers, by breaking down the total cost into: capital, fuel, lubricants, operational and maintenance costs. More specifically into transportation and the integration of piecewise linear cost functions into network design decisions, Sheng, Dechen & Xiaofei, (2006) investigate the transportation problem with discontinuous piecewise linear cost function (TPDPLC). They argue that TPDPLC can be easily formulated and solved as a MILP, and theoretically any general MILP could be used to solve this kind of problem, however due to computational requirements, metaheuristics methods can lead to good solutions, and the genetic algorithm proved itself to be the most suitable for their work. Görtz & Klose (2007) study the single-sink fixed-charge transportation problem (SSFCTP), which consists in finding a minimum cost flow from a number of supplier nodes to a single demand node. In this transportation problem, shipping costs comprise costs proportional to the cargo as well as a fixed-charge. Authors refer that, though it is a very important relaxation from the fixed-charge transportation problem, it has not attracted much attention in the literature, with only a few authors actually developing meaningful insights. The applications for the SSFCTP were first referred in 1996, according to the authors, and include the areas of manufacturing and transportation, namely in supplier selection, product distribution/fleet selection and process selection. Christensen (2013) composes his thesis by addressing three different problems with commonalities between them, since all of them are related to Network Design and consider a piecewise linear cost structure. The beginning of the author’s work reflects an overview of different facility location models, using non-standard production and/or transportation cost function such as the piecewise linear cost function, with the aim of categorizing existing literature, which led to the conclusion, as previous authors, that the area of non-standard transportation costs had only been sparsely treated in literature. Furthermore, he focuses on the single-sink fixed-charge multiple choice transportation problem (SSFCMCTP) by presenting an efficient dynamic programming algorithm to solve it. Then, the work leans on more general capacitated facility location with piecewise linear transportation costs problems.

Modelling transportation and inventory costs

Dhakry & Bangar (2013), stress the fact that there are two important topics in the supply chain that contribute to the total cost of the supply chain network: transportation and inventory costs. With that in mind, companies can achieve significant savings by considering these two costs at the same time rather than trying to minimize each separately. Three in-stock strategies are studied in their work – flow through, regional and single DC central stock – and they develop a simple transportation-inventory model to compare the total costs of each strategy. A distribution model is also formulated as a non-linear integer optimization problem, and due to the non-linearity of the inventory cost in the objective function, two heuristics and an exact algorithm are proposed.

Also, Swenseth & Godfrey (2002) work aims at incorporating transportation costs into inventory replenishment decisions, as the need to develop models with appropriate representation of transportation considerations is further enhanced. So they propose a solution procedure, based on the economic order quantity model (EOQ) and further modifications, that systematically solves inventory replenishment problems, using a classification of shipping decisions according to whether shipments can (or are) declared as full truck loads or not. Zeng, Hu & Huang (2013) analyze the transport allocation problem in a multimodal transportation environment for automotive logistics, by using a genetic algorithm that can minimize logistics costs.

Incorporating sustainability into transportation decisions

Due to the current growing concern with environmental issues and sustainability in the SC, there is also an increase in literature research focus to attempt to integrate sustainability and green logistics aspects into transportation decisions. Dekker et al. (2012) present a review that highlights the contribution of Operations Research (OR) to green logistics. Ji, Wu & Zhu (2015) address the issue of eco-design for transportation in SSCM, using and extension of Data Envelopment Analysis (DEA) and its combination with a developed tractable algorithm. Tang et al. (2015) evaluate the issue of cutting emissions by reducing shipment frequency within a periodic inventory review system environment. Validi, Bhattacharya & Byrne (2014) look at the distribution side from producers to customers in terms of sustainable supply chain management with a green multi-objective optimization model that minimizes CO2 emissions from transportation and total costs in the distribution chain. Existing literature on economic and environmental concerns along with social repercussions is rare, hence is important to remark the study by Ramos, Gomes & Barbosa-Póvoa (2014) in which they aim to provide support at tactical and operational decision making levels of reverse logistic systems planning, while considering economic, environmental and social objectives. Authors then model the problem as a multi-objective, multi-depot periodic vehicle routing problem with inter-depot routes.

3. PROBLEM STATEMENT

This challenge began with the identification, from Autoeuropa, of a particular behavior regarding transportation inbound rates for certain suppliers in certain countries. This behavior, as explained before, presented characteristics of a non-decreasing piecewise function, with constant segments and others that increased in a fairly linear manner according to the cargo weight. Having identified the existence of these unusual structures, the objective was to narrow the countries in which that kind of cost structure was present and consequently consider the suppliers present in those countries. Furthermore, it was intended to analyze how those rate profiles could be used in an advantageous way for the firm, especially when cargo's taxable weight fell into the constant price segments, since the comprehensive knowledge of those prices could allow to increase cargo sizes until the limit of the segment, and thus exploring scenarios of less frequent shipments. Of course transportation scenarios have impacts on inventory, since the reduction of frequencies implies an increase in order quantities and therefore stock build-up.

4. APPROACHES EXPLANATION

In order to solve and propose improvements on the current scenario, two approaches were developed: a manual approach exploring excel and an optimized approach.

4.1. Manual Approach

First, a manual analysis was performed for each supplier, in which different scenarios were studied by changing the frequency of orders to a biweekly or a monthly scenario. Also, given the high level of detail associated with this approach it was also analyzed for some suppliers a scenario of quantity changes, with the goal of increasing some units in every order in order to accumulate stock – and simultaneously take advantage of the constant step of the function in which the current order was – and reach a week in which it was not necessary to place an order.

This approach was performed using the potentialities of Microsoft Office Excel, and it had under consideration the forecasted deliveries, packaging type, packaging dimensions, number of parts per packaging and product weight. The forecasted orders allowed to understand what the necessary quantities were and the remaining data led to the total taxable weight. For the other proposed scenarios – biweekly, monthly, and quantity increases -, the forecasted deliveries were altered to reflect those delivery scenarios and calculations to obtain total taxable weight were performed using those new values. Furthermore, impact on inventory was assessed by analyzing the material requirement planning for each product, as to know the quantities of product that were required to feed the line per week, and by performing an inventory balance calculation, to determine the increase in the average stock per week that each scenario would provoke. The manual approach was then automatized into an Excel tool to aid Autoeuropa transportation planners.

4.2. Optimization Approach

Regarding the optimization approach a mathematical model was developed from scratch. In this, different products can be delivered by different suppliers into a single destination point. Products – raw materials and parts – can only be supplied by one supplier, yet one supplier can be responsible for the delivery of more than one product.

Generically, the problem can be described in the following summarized form:

Given:

- Transportation cost function
- Material Requirement Planning for each time in each time period
- Established maximum capacity of vehicles
- Products information: prices, etc.
- Stock opportunity cost

Determine:

- Optimum quantities from supplier to destination
- Optimum delivery frequencies

With the goal of minimizing transportation and inventory costs.

Mathematical formulation

Sets/Indices

I Set of suppliers *i*

T Set of time periods *t*

P Set of products *p*

L Set of possible lots *l*

$P(i)$ Set of products *p* supplied by supplier *i*

J Set of possible breakpoints *j* in the piecewise transportation cost function.

A Set of countries α

Parameters

C_p - Price per product *p*

$COpp_p$ - Opportunity cost per product *p*

$OppRate$ - Opportunity rate

$istock_p$ - Initial stock per product *p*

SS_p - Safety stock per product *p*

$maxCap$ - Maximum allowable capacity

$nPPP_p$ - Number of unit products per product package

$TWFactor_p$ - Taxable weight factor per product *p*

$a_{i,j,\alpha}$ - Cost parameters (y-axis) for piecewise cost function per supplier *i*, in breakpoint *j* and country α

$b_{i,j,\alpha}$ - Weight parameter (x-axis) for piecewise cost function per supplier *i*, in breakpoint *j* and country α

Variables

$x_{p,t}$ - Quantity of product *p* to be ordered in time *t*

$z_{i,t}$ - Transportation cost per supplier *i* in time *t*

$w_{i,t}$ - Cargo weight value per supplier *i* in time *t*

$lots_{p,l}$ - Lot sizes *l* possible to be ordered per product *p*

$nPack_{p,t}$ - Number of packages per product *p* in time *t*

$TW_{p,t}$ - Taxable weight per product *p* in time *t*

$TWS_{i,t}$ - Taxable weight per supplier *i* in time *t*

$stock_{p,t}$ - Stock quantity per product *p* in time period *t*

$SCP_{p,t}$ - Total stock cost per product *p* in time period *t*

$SCS_{i,t}$ - Total stock cost per supplier *i* in time period *t*

$\lambda_{i,j,t,\alpha}$ - Positive variable, coefficients for the piecewise cost function linearization, for supplier *i* for country α, breakpoint *j,* in time *t.*

Binary

$y_{p,l,t}$ - Binary variable, 1 if lot size *l* per product *p* in time *t* is selected; 0 otherwise

$v_{i,j,t,\alpha}$ - Binary variable, 1 if the breakpoint *j* of the cost function for supplier *i* in country α is selected in time *t; 0* otherwise.

Objective Function

$$minimize \sum_i \sum_t z_{i,t} + \sum_i \sum_t SCS_{i,t} \quad (1)$$

Subject to:

$$x_{p,t} = \sum_l y_{p,l,t} * lots_{p,l,}, \quad \forall p \in P, t \in T \quad (2)$$

$$nPack_{p,t} = \sum_l \left(\frac{x_{p,t}}{nPPP_p}\right), \quad \forall p \in P, t \in T \quad (3)$$

$$TW_{p,t} = nPack_{p,t} * TWFactor_p, \quad \forall p \in P, t \in T \quad (4)$$

$$TWS_{i,t} = \sum_{p \in P(i)} (TW_{p,t}), \quad \forall i \in I, t \in T \quad (5)$$

$$\sum_l y_{p,l,t} = 1, \quad \forall p \in P, t \in T \quad (6)$$

$$z_{i,t} = \sum_j a_{i,j} \lambda_{i,j,t} \quad (7)$$

$$\forall i \in I, t \in T, \; j = 1 \; until \; the \; maximum \; number \; of \; breakpoints \; in \; a \; function$$

$$w_{i,t} = \sum_j b_{i,j} \lambda_{i,j,t} \quad (8)$$

$$\forall i \in I, \boldsymbol{t} \in \boldsymbol{T}, \; j = 1 \; until \; the \; maximum \; number \; of \; breakpoints \; in \; a \; function$$

$$\sum_{j=1}^{n} \lambda_{i,j,t,\alpha} = 1, \; \forall i \in I, t \in T, \alpha \in A \quad (9)$$

$$\sum_{j=1}^{n} v_{i,j,t,\alpha} = 2, \quad \forall i \in I, t \in T, \alpha \in A \quad (10)$$

$$\lambda_{i,j,t,\alpha} \leq v_{i,j,t,\alpha}, \forall i \in I, t \in T, \alpha \in A, \; j \in J \quad (11)$$

$$v_{i,j,t,\alpha} + v_{i,j+s,t,\alpha} = 1, \quad \forall i \in I, t \in T, \alpha \in A, j \in J, s = \{2, \ldots, n-1\} \quad (12)$$

$$stock_{p,t} = istock_p + x_{p,t} - mrp_{p,t} \quad , t = t_0, \forall p \in P \quad (13)$$

$$stock_{p,t} = stock_{p,t-1} + x_{p,t} - mrp_{p,t} \quad , t \neq t_0, \forall p \in P \quad (14)$$

$$stock_{p,t} \geq SS_p \quad , \forall t \in T, p \in P \quad (15)$$

$$TWS_{i,t} \leq 1000 \quad (16)$$

$$COpp_p = OppRate * C_p \quad (17)$$

$$SCProduct_{p,t} = stock_{p,t} * COpp_p \quad (18)$$

$$SCS_{i,t} = \sum_{p \in P(i)} stockCost_{p,t} \quad (19)$$

$$w_{i,t} = TWS_{i,t} \quad (20)$$

The model presented can be explained as follows: First, the objective function (1) minimizes the total costs of the transportation activity, with its first term relating to the transportation costs directly, as a function of the supplier and the cost structure that has been discussed previously; then the second term regards inventory costs, so it is the total cost

for the analyzed period of time of the stock build-up.
Equation (2) relates to the quantity that should be ordered, of each product in each moment, stating that the quantity to order can only be one of the options that belongs to the set of lots, which define the fixed quantity sizes. Equation (3) uses the quantity to be ordered divided by the parameter of the number of parts per package in order to translate the quantity into package units.
Equations (4) and (5) are calculations for the taxable weight. The first one is per product and shows how the taxable weight depends on the number of packages and the factor – which is the highest unitary value between weight and volume as explained in previous chapters.
The second formula shows the summation for suppliers, according to the set of products of the supplier. For Portugal, these values do not interfere with transportation costs, however they are fundamental for the model for suppliers in Spain and France.
Equation (6) relates to equation (1), as it is a constraint that forbids that more than one lot size is chosen for the quantity to be ordered for each product in each time period.
Equation (7) and equation (8) represent the ordinates and abscissas values for the transportation cost calculation, as it has to be modeled following the linearization of piecewise function explained in the previous section
Equation (7) stands for the transportation cost, which is the sum of the possible ordinate breakpoints values multiplied by the lambda parameter that defines the two breakpoints "active" in that time period. The same logic follows for equation (8), however $w_{i,t}$ represents the x-axis values of the breakpoints, meaning total taxable weight per supplier.
Equation (9) is the statement that guarantees that the sum of parameters "lambda" equals one for each supplier in each time period. Equation (10) guarantees that only two binary variables $v_{i,j,t,\alpha}$ are active and consequently only two breakpoints are selected in the cost function to define costs in that period of time. Thus, equation (11) guarantees that those two breakpoints are consecutive by preventing non-consecutive points of being active at the same time.
Equations (12) to (13) concern inventory constraints. Both equation (12) and (13) are material balances, for the first time period and the following ones, respectively. Here is stated that inventory for a product during a week is the sum of stock from the previous week (or initial stock for equation 12) plus the quantity that is received that week minus the requirements of that material. Equation (14) guarantees that stock levels are never below the defined safety stock for the product.
Equation (15) is related capacity limitations. However, as explained before, this is not an actual physical constraint from the truck, but it regards the defined scope of this project in terms of maximum taxable weight that is studied to avail from the stepwise cost structures.
Equation (16) models the calculation for the opportunity cost in which inventory is valued as the result between the opportunity rate chosen by the company and the price of the product.
Equations (17) and (18) are support calculations that show how the inventory cost is calculated per product and then per supplier, by summing on the set of products belonging to the supplier. Finally, equation (19) states that the total taxable weight per supplier is the value for the abscissas in the cost function. Equation (20) equals the abscissas to the taxable weight.
The final model results in a mixed integer linear programming model (MILP) that was implemented in GAMS.

5. RESULTS

The approaches explained previously were applied to the case study. First, the manual approach with three frequency scenarios was considered: biweekly, monthly and quantity changes. Following, the mathematical model was applied to optimize and analyse the current frequency delivery situation at AE.

5.1. Manual Results for Portugal

The impact – when compared with the original scenario - of biweekly and monthly scenarios analyzed for portuguese suppliers are shown in table 1 and 2. It can be seen that these scenarios lead to transportation savings, but that the final result for most of them is negative due to the excessive cost of inventory these scenarios encompass. Some suppliers were not analyzed on biweekly scenarios due to the fact that their current frequency scenarios were already very similar to biweekly.

Table 1 - Manual Results for Biweekly Scenario in Portugal

Impact (WK 8-20)	Biweekly			
	Transportation	Inventory	Rental	Total
Supplier 1	- 86,31 €	8,12 €	0,04 €	- 78,15 €
Supplier 2				
Supplier 3				
Supplier 4				

Table 2 - Manual Results for Monthly Scenario in Portugal

Impact (WK 8-20)	Monthly			
	Transportation	Inventory	Rental	Total
Supplier 1	- 155,36 €	21,23 €	0,09 €	- 134,04 €
Supplier 2	- 136,22 €	1 020,38 €		884,15 €
Supplier 3	- 77,82 €	654,65 €	0,57 €	577,39 €
Supplier 4	- 119,43 €	3 240,05 €	0,18 €	3 120,80 €

5.2. Manual Results for Spain

Table 3, 4 and 5 show the impact of the three scenarios assessed for Spain. Also, some suppliers were not analyzed on monthly scenarios, as the junction of cargo would largely exceed the constraints defined for the scope of this work. Therefore, a third scenario arose – the quantity changes scenario – with the goal of increasing some units in each order as to avail from the constant step of the piecewise cost function and then reach a week were it would not be necessary to order, as needs would be covered by built stock.

Table 3 -Manual Results for Biweekly Scenario in Spain

Impact (WK 8-20)	Biweekly			
	Transportation	Inventory	Rental	Total
Supplier 1				
Supplier 2				
Supplier 3	- 39,49 €	4 615,81 €	2,89 €	4 579,21 €
Supplier 4				
Supplier 5				

Table 4 - Manual Results for Monthly Scenario in Spain

Impact (WK 8-20)	Monthly			
	Transportation	Inventory	Rental	Total
Supplier 1	- 127,58 €	1 863,25 €	2,84 €	1 738,52 €
Supplier 2	- 423,63 €	1 554,44 €	8,33 €	1 139,14 €
Supplier 3				
Supplier 4	- 156,38 €	294,69 €	1,01 €	139,32 €
Supplier 5				

Table 5 - Manual Results for Quantity Changes Scenario in Spain

Impact (WK 8-20)	Quantity changes			
	Transportation	Inventory	Rental	Total
Supplier 1	- 97,39 €	32 876,73 €	4,51 €	32 783,86 €
Supplier 2				
Supplier 3	115,23 €	224,46 €	0,03 €	339,71 €
Supplier 4	- 158,63 €	7 395,87 €	1,16 €	7 238,39 €
Supplier 5	9,51 €	5 912,65 €	0,57 €	5 922,74 €

The observation of the tables shows that there are positive savings in transportation for mostly all suppliers, but similarly to the portuguese case, inventory precludes the potential overall savings. It is important to notice that for some suppliers, the quantity changes scenario did not prove to be advantageous. This scenario was proven to be beneficial for suppliers with only one product, because for the others there were either a jump in the cost function – increasing costs – or only one product was increased and the remaining ones still needed to be ordered at the same previous weeks.

5.3. Manual Results for France

The results of both scenarios analyzed for this country when compared to the original are summarized in Table 6 and 7.

Table 6 - Manual Results for Biweekly Scenario in France

Impact (WK 8-20)	Biweekly			
	Transportation	Inventory	Rental	Total
Supplier 1	- 77,18 €	1 068,23 €	9,25 €	1 000,29 €
Supplier 2	- 158,95 €	48,90 €	0,10 €	- 109,94 €
Supplier 3				
Supplier 4				
Supplier 5	- 183,45 €	2 964,18 €	16,80 €	2 797,53 €
Supplier 6	- 33,70 €	81,18 €	0,01 €	47,49 €
Supplier 7	- 108,59 €	417,06 €	0,69 €	309,17 €
Supplier 8	- 357,30 €	6 473,99 €	10,35 €	6 127,03 €

Table 7 - Manual Results for Monthly Scenario in France

Impact (WK 8-20)	Monthly			
	Transportation	Inventory	Rental	Total
Supplier 1	- 34,65 €	3 453,94 €	32,37 €	3 451,65 €
Supplier 2	- 209,46 €	162,20 €	0,51 €	- 46,75 €
Supplier 3	- 44,44 €	551,12 €	0,64 €	507,32 €
Supplier 4	127,12 €	870,49 €	1,00 €	998,61 €
Supplier 5	- 192,27 €	19 449,18 €	26,66 €	19 283,58 €
Supplier 6	- 134,78 €	222,65 €	0,02 €	87,89 €
Supplier 7	- 149,54 €	1 668,26 €	2,77 €	1 521,49 €
Supplier 8	- 1 489,37 €	18 342,96 €	29,31 €	16 882,91 €

Results show, as with the previous countries, that these scenarios allow for transportation savings for almost all suppliers. However, only one of the suppliers has an overall positive situation, which is supplier 2.

Furthermore, it can be seen that supplier 4 has increased transportation costs in the monthly scenario, explained by the fact that cost functions in this country have small constant steps and thus the increase of quantity in this scenario leads to the cost values jumping onto the following piece of the piecewise function, increasing total transportation costs, though unit costs are reduced.

5.4. Optimization Approach Results

Overall, the mathematical model aimed to provide the optimum quantities to be ordered from a supplier, having under consideration the possibility of availing piecewise transportation cost structures, leading to reduced frequencies that could cost the same per frequency and thus reducing transportation costs. At the same time, the model considered the minimization of inventory costs, which are highly dependent on the quantities to be ordered. Therefore, there was a challenge in trying to obtain the best combination of orders from each supplier and for each product while having the capacity to assess the trade-off between two fundamental costs for logistics. Given so, overall results for the countries under analysis are summarized in Table 8 and 9.

Table 8 – Total Transportation Results (Model)

Transportation	PORTUGAL		SPAIN		FRANCE	
Original Quantity	123 488		176 960		326 770	
GAMS Quantity	112 976	-8,5%	176 210	-0,4%	303 788	-7,0%
Original Cost	759,53 €		3 084,89 €		7 445,24 €	
GAMS Cost	569,65 €	-25,0%	3 040,27 €	-1,4%	6 603,90 €	-11,3%

Table 9 – Total Inventory Results (Model)

Inventory	PORTUGAL		SPAIN		FRANCE	
Original Quantity	590 519		327 264		670 271	
GAMS Quantity	302 379	-48,79%	310 738	-5,05%	505 007	-24,66%
Original Cost	85 844,34€		191 707,96€		346 067,59€	
Cost GAMS	53 357,00€	-37,84%	133 682,35€	-30,27%	284 760,14€	-17,72%

From both tables is possible to conclude that the mathematical model allows to significantly improve quantities and costs for all countries.

This is however an overall result, and there are in fact some suppliers within the countries that increased costs in one of the areas – whether transportation or inventory – due to the fact that the model tries to balance the sum of both costs. Given the fact that inventory valorization is fully proportional to the cost of the product, the rationale supporting these results is sustained on the high costs some of the products have and, simultaneously, on the very reduced costs some other possess, which allows the model to increase the quantity of those that are not that expensive – possibly reducing transportation frequencies and costs - and therefore will not impact as strongly the final result as well as decrease the quantity – possibly also augmenting frequencies and resulting in higher transportation costs - , and consequently the stock costs, of those that are more costly.

5.5. Scenarios Comparison

Overall, the two different approaches applied to the case study led to different results that are summarized in Tables 10, 11 and 12 for each country. This tables show the total costs for all scenarios analyzed under the current conditions (opportunity cost) and its percentage comparison to the original scenario – green and negative means savings and red and positive means increased costs. From its observation, along with the results that were shown in the previous sections, it is possible to conclude that, though manual scenarios have very positive transportation savings for mostly all suppliers, their total results are deeply jeopardized by the increased inventory costs, resulting in final values that are not so advantageous for all suppliers.

Table 10 - Scenarios Comparison for Portugal

	TOTAL COSTS	PORTUGAL	
	ORIGINAL	8.485,52€	
MANUAL	BIWEEKLY	8.407,33€	-1%
	MONTHLY	12.932,99€	52%
MODEL	GAMS	5.371,78€	-37%

Table 11 - Scenarios Comparison for Spain

	TOTAL COSTS	SPAIN	
	ORIGINAL	20.338,61€	
MANUAL	BIWEEKLY	20.807,61€	2%
	MONTHLY	23.630,03€	16%
	QUANTITY CHANGES	24.370,10€	20%
MODEL	GAMS	15.071,68€	-26%

Table 12 - Scenarios Comparison for France

	TOTAL COSTS	FRANCE	
	ORIGINAL	38.591,32€	
MANUAL	BIWEEKLY	48.725,71€	26%
	MONTHLY	81.184,74€	110%
MODEL	GAMS	32.232,31€	-16%

On the other hand, the mathematical formulation proved to significantly optimize the current scenario by values between 16% and 37%, as seen in the last row of the above tables, thus revealing that the current methodology of orders forecasting might not be the most advantageous for the company.

5.6. Sensitivity Analysis

During the development of this work, there was a constant preoccupation regarding the parameter of opportunity cost considered by the company. This value is directly related to inventory valorization, since the calculation is based on the multiplication of the average stock level, the product price and the opportunity cost. The value used by AE, is 9%, meaning that the company assumes that the money that is tied up in inventory could result in an interest rate of 9% if invested in an alternative financial application. Given the current market and financial conditions, this does not seem like a feasible scenario, which is why this parameter is further studied in this section, in order to assess how its reduction, to more real values, could impact the analysis previously presented.

The parameter was submitted to 1% reductions, from 9% until 3% Results show this parameter precludes all the manual scenario analysis and it also reduces the potential of savings from the mathematical model. Given the fact that it is out of sync with the current market values, it is advised that the company reconsiders its inventory valorization policy, as it might be hampering great savings.

6. CONCLUSIONS

In this work the inbound logistics of an automotive manufacturing plant regarding the replenishment decisions with incorporation of transportation and inventory costs is analysed.

Two approaches were developed: a manual approach that led to the development of an Excel tool; and an optimization model which integrates simultaneously transportation and inventory costs in order to provide the best schedule of orders that minimizes the impact on both variables.

Results obtained show that there is potential for transportation savings and that the current forecasting method at the company might not be the most advantageous. However, the company needs to confront the improved results – which are obtained having a series of assumptions and simplification under consideration – with real constraints.

As future work development a few suggestions arise regarding: broadening the sample of suppliers, relaxing the capacity constraints, verify the applicability of scenarios with suppliers, modelling environmental impacts as an objective variable. To conclude, though there are aspects that can be improved in future steps, it is expected that this work stands as a meaningful contribution to the academic community about the study of piecewise transportation cost functions in a real example and that the developed work can be of extensive usefulness for the decision making process of Autoeuropa's transportation planners.

Original contributions and potential impact

It is remarkably important to notice that this work was developed completely by the author, with all the tools and developed model being built by the author from scratch, having as inspiration the existing literature but with the concern of developing a model that could be general enough to constitute an important contribution for the academic community as well as sufficiently incorporative of the case study specificities. This work intends to fill the void that was perceived in the literature research regarding the combination of the single sink transportation problem and the transportation problem with discontinuous piecewise linear costs, while also incorporating the essential concerns with the impact transportation decisions have in the remaining logistic activities, more specifically inventory repercussions. Therefore, the developed work provides a solid basis for further studies in the area of replenishment decisions that can minimize costs while simultaneously considering stock costs and transportation costs, with the very important characteristics of the transportation cost structure not being linear and completely proportional to cargo weight, as most of the literature case studies consider. Also, and with high importance, is the fact that the company under study, VW AE, was provided with a tool that can aid transportation managers in taking more efficient decisions and incorporating all the knowledge that was now understood and identified by the development of this work in the company. Furthermore, an academic paper will be written and published in the following year in an academic magazine

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