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REDUCING GAS EMISSIONS THROUGH SUPPLY CHAINS COLLABORATION: LESSONS FROM FRENCH RETAIL CHAINS

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ABSTRACT : Consolidation of shipments is an old subject in supply chain management, however as the supply chain concepts spread over the firms there is still little concerns about using it to reduce the environmental logistic footprint of these operations. What will be the reduction in gas emissions if firms, buyers and sellers or even competitors firms, start an horizontal collaborative process and share logistic assets such as warehouses or transportation means ? First we will summarize consolidation principles at supply chain level that could lead to freight consolidation or transportation substitution therefore greening the supply chain. Based on these principles several scenarios was studied. These scenarios were driven by actual firms logistic data and for that reason represent a good estimate of the emissions potential of savings. The main finding of this research is the possible saving of at least 25% of emission by the proposed transportation organization. The impacts of the different scenarios on assets use and on gas emissions will be discussed.

KEYWORDS : *Gas emissions, Freight consolidation, Retail*

1 INTRODUCTION

1.1 Motivation

Since the economy became more global, the supply chain has to cope with the new opportunities and complexity to serve more customers from more distant and spread producers. This was done having mostly in mind cost and service level goals. As large inventories were not acceptable, this was mostly achieved with high frequency deliveries. Therefore the supply of common goods from the producers to the stores made an intensive use of transportation assets and logistic facilities. As a matter of fact the freight transportation measured as ton.km grown faster than the GDP or the industrial output in the last decade in EU . In the same time, we are getting more aware of the environmental effects of these operations, such as green house gas emissions. So one can expect increase in the transportation cost by oil price or by taxes and even limitation policies, see for instance , witch might have in return an eminent impact on supply chains structure and organization.
Having that in mind the French industrials and retail chains logistic heads create an association with the purpose of defining a more environment friendly supply chain. This association named *Club Déméter* is a committee where logistic executives share ideas and give support to selected studies. This committee granted the present research project and gives the researchers full support to obtain information from the firms' databases.
The French retail chains can be globally seen as a 3 echelons supply chain, see figure 1. This supply chain is mainly a national supply chain as the majority of plants are located in France. As the plants are specialized and have no stock, the warehouses (WH) play a double task. First they carry inventories but they are also used to aggregate and serve the full product line. Each company own or operate via a third party logistic (3PL) very few warehouses per country. The distribution centers (DC) are regionally based, few are owned and the vast majority is operated for the retail chains by a 3PL. The distribution centers serve the stores directly for big supermarkets or via multi-deliveries trip for the small ones. Both on the industrial and the retail sides, firms that compose the supply chain are more or less direct competitors.

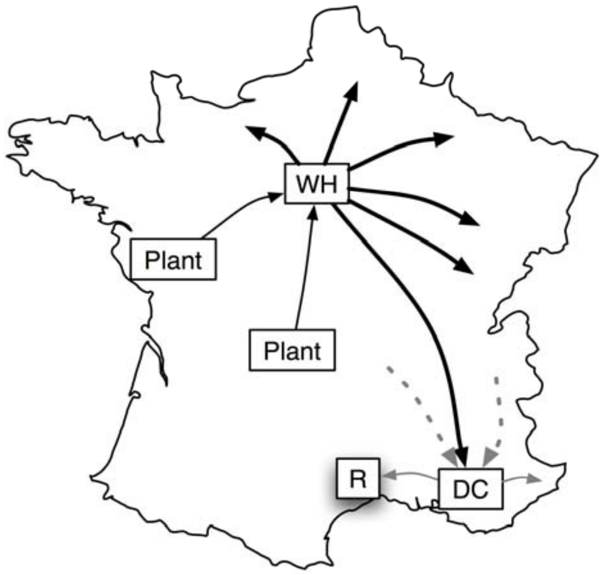

Figure 1: French retail chain typical supply chain excerpt from a plant to a retail store

Basically, this research project investigates the environmental impact of partially merging several supply chains belongings to different industrials and retail. For this purpose a brief description of data collection will be given after the literature review. As the collaboration can be achieved in many ways, the principles used here will be presented and linked to the literature before the selection of scenarios and their presentation. In every case, despite the fact the firms driven supply chains was already vertically well optimized, the first result of horizontal consolidation is a 2 digits reduction of gas emissions. However, it is not the only leverage found. As volumes are building up, other transportation means, which have a smaller environmental impact, might substitute to trucks such as rail or barge. In this case the environmental impact will be mainly observed by the reduction of CO2 emissions taken here as an indicator of the whole emissions.

1.2 Literature review

In the past years collaboration through the supply chain as been mainly seen as a vertical collaboration witch leads to synchronization by sharing information . However, and even if less attention was put on this subject, horizontal collaboration is also possible as recently pointed out . In the research we will look for horizontal supply chain collaboration to reduce emissions.

There are many possibilities to reduce the environmental footprint of a supply chain: alternative energy… see Tsoulfas for a review . Among them the organization of freight transport is not always very much seen as an issue, even if Vanek draw attention to the potential of more energy efficient freight transportation . The same conclusion was established in a survey by Leonardi et al. with a very strong correlation between transportation efficiency and CO2 emissions . These results highlight the fact that any reduction of empty legs or any increase in truckload will have a great impact on CO2 emissions. In the literature we founded many papers on freight consolidation that will be discussed in this review as well as several cases studies. We looked primarily to environmental cases studies but as there are very few, freight consolidation case study will also be taken into consideration.

Consolidation is not a new problem in transportation research and many publications can be founded on this topic. It as been found since long that consolidating small freight shipments into vehicle loads allows more efficient and frequent shipping by concentrating large volumes onto relatively few transportation links. This problem is formulated at different decision levels, from the design of a distribution network to the freight consolidation within vehicles at an operational level. Most of time this problem is seen as dynamic problem of minimizing truck repositioning or routes optimization for less than truckload trips. This approach mainly address the problem faced by the carrier or the shipper at the operational level. In this paper we will focus at the design level. This problem can be idealized in a many-to-many logistics network consolidation problem where carriers take advantage of transportation economies of scale. Even if the traveled distance is often greater than by direct shipment the better usage of transportation means reduce the overall cost see or .

Although these techniques are somehow embedded in optimization software now widely used by retail chains and industrials, surveys point out that room for improvements is still there. An extensive survey of the transport efficiency in the UK food supply chain made in 2003 revealed that the loaded trips had an average of 65% of the available pallet positions occupied . And this indicator was much better than the weight ratio. This fill rate in pallet was better in the upstream of the supply chain, from factories to industrial warehouses, and worse from regional distribution centers to supermarkets. Those numbers are partially confirmed by another survey due to a different categorization of transportation usage .

In our research in the literature about collaboration between shippers we found very few cases studied. The first case comes from Pajala in Sweden and was primarily an attempt to integrate the transportation for far from all companies in a small economic area. As mean truck load was low (60%), the coordination of

transportation was found to be a solution for these companies to compete with other supply chains, by the opportunity they will have to send and receive goods any day they want for shortening the delivery times to customers . This case mainly deals with small volume and long distance, by coordination of carriers. A more similar to our question case study was made by Groothddle et al. in Netherlands . In this case, a collaborative multimodal hub network is designed to decrease logistics cost and maintain logistics service levels by shifting consolidated flows to modes that are better suited for handling large volumes (rail, barge, coastal shipping). Through collaboration the necessary synchronization between expensive but fast and flexible means of transport and inexpensive, but slow and inflexible means are combined. The authors report that a commercial pilot with a logistics service provider and a barge operator was about to start in January 2004.
Another important actor for freight consolidation is the “third party logistic” or 3PL. With all their assets, customers and netwoks, one can expect a supply chain to be more environmental by using a 3PL. We were not able to find a study on the impact of the 3PL on emissions. However it has to be pointed out that most of the results from the surveys already take into account 3PL.
The goal of this research is to demonstrate that the principle of merging supply chains means may lead to significant reduction of emissions. In the next part (§2) the concept of supply chains merging will be defined. In a following paragraph (§3) the sets of data used to demonstrate the meaningful of the concepts will be presented and commented as well as the methodology used to compute emissions.

2 SUPPLY CHAINS MERGING PRINCIPLES

2.1 Consolidation at a supply chain level: merging supply chains

As indicated above there is a vast literature about freight consolidation at the carrier level, mostly at an operational level and treated as dynamic optimization problems. In this research we are looking for supply chains consolidation. It means that several industrials or retail chains will accept to share information and to cooperate in order to find a better design for their supply chain or part of it by defining a new one with some common parts. The common physical parts of the supply chain, that could be shared are: transportation means, warehouses and distribution centers. This leads to partially merge competitor supply chains.

To usefully merge, the partners could already belong to the same global inter firms supply chain, for instance the automotive industry can share logistic assets. But this is not a necessary condition; the only requirement is to share common geographic areas and not exclusive products (food can not be transported with dangerous chemical products, or gaz, etc.).

2.2 Generic merging principles

As stated above, consolidation appeal to attention from the research community for years and definitions was proposed by Hall and Pooley, see . The definitions proposed by Hall make distinction between: inventory consolidation when time is given for consolidation, vehicle consolidation when a vehicle arrange his trip to visit several shippers and terminal consolidation when several transportation means converge to a terminal where the freight is sorted and shipped to the final destination (hub). Pooley named the terminal consolidation network consolidation and distinguish two sub case in the vehicle consolidation called vehicle consolidation and shipment consolidation.
In this work we will consider consolidation at the supply chain level. It means that any facility such as warehouse, distribution center, hub can be put in common for several supply chain. Figure 2 illustrates this principle applied to warehouses. Naturally, the same criteria than for freight consolidation applied: geographic proximity to avoid detours that will ruin the consolidation scale effect.

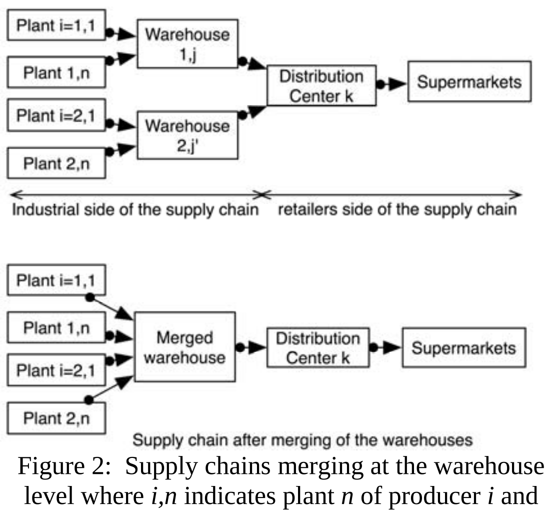

Figure 2: Supply chains merging at the warehouse level where *i,n* indicates plant *n* of producer *i* and where *j* is the index of the warehouse

Our work will focus on the stakes resulting from horizontal collaboration, so organizational issues that could raised we will not discussed here.

3 THE SUPPLY CHAIN MODEL

3.1 Data from 2 major retail chains

Data came mainly for two majors retail chains in France. These databases were also completed and checked by data brought by industrial firms. The data provided to us covers the first 20 weeks of 2006. The whole country is covered by the data from all the warehouses and some plants to the supermarkets for drinks, grocery and care. These families of products were chosen because of their different behaviors and their relevance: drinks are heavy products with seasonal demand, grocery are common products and personal cares faced low volume, extended product range. The database allows working at a week level and at a sub family product level. The week level means that we know how many pallets were delivered within the week. The sub family level for instance within the drinks family allows to make the difference between water or soda (high volume products mainly delivered to supermarkets as full homogeneous pallets) and alcohols (low volumes delivered by boxes). The sub family level is also required to avoid inappropriate freight consolidations.
The first task was to build a unified data framework for data sets from different origins and with different codifications especially for sub families. The common producers were retrieved within the top 200 in turnover of each retail chain, with a goal of a top 100 common producers. The final list has 106 producers; each producer can serve one or several of their warehouses or ships directly to a distribution center from the plant. The warehouses serve the distribution centers, but not necessarily all of them as they can be specialized by product familly. The product families were also put on a common basis (see table 1 for details).

Data	Producer	WH	DC	Product family
Retail chain 1	200	NA	43	71
Retail chain 2	200	NA	16	101
Common	106	164	0	50*
Used	106	164	59	50

Table 1: Supply chains data.

It can be noticed that each producer holds few warehouses, for instance one for the north of the country and one the south and each retail chain holds several distribution centers per region according to their degree of specialization.
Within this unified data framework the flows are characterized in table 2. It can be noticed in this table that the weekly flows shipped from a warehouse to a distribution center feature great volumes variability, due to the seasonal effect, replenishment policy but also due to special commercial offers.

Product	Mean distance / link (km)	Std deviation distance /link	Sum flows/week (pallet)	Mean flows / link and week (pallet)	Std deviation flow / link and week (pallet)
Drinks	371	206	66 645	28.6	62.1
Grocery	331	198	61 622	14.2	25.2
Care	354	202	26 055	21.3	35.2
Total	346	202	154 322	19.6	41.5

Table 2: Supply chains flows between WH and DC

The simulation model build to demonstrate the interest of the presented concepts is based on 3 stages. The first stage computes the weekly flows between origins and destinations according to the current situation and the merged SC scenario. The second stage of the model looks for the minimum of transportation means needed on each linehaul with actual flows per week as constraints. It means that we are not looking for a better transportation solution by reducing delivery frequency and adding stocks. The third part of the model computes the gas emissions as explained in the following paragraph.

3.2 CO2 emission models for transportation

Freight transportation emissions cover a broad range of pollutants gases and particles. Among them there is CO2. This particular pollutant was chosen not only for its well known green house effect but also because transportation accounted for 28% of the total CO2 emissions within the EU, see moreover, the amount of CO2 released by transportation is still expected to grow. In France, the transportation made by heavy trucks account for 21.7% of the total CO2 transportation emissions, see .
The methodology used here to compute the CO2 emissions comes from the Deliverable 22 of the European MEET project . This report is taking place in an undergoing effort of the EU to relate the use of all transportation means to their emissions according to the type of vehicle or engines, for more details on MEET or COST 319 European projects, please refer to .

* The common families are not a direct intersection but the result of designations adjustments.

Using provided formulae, it's possible to express the CO2 emissions in g for truck e_v and railway car e_c respectively as a factor of speed, load ratio and traveled distance. The adapted formula is given here for truck with gross weight from 32 tons to 40 tons :

$$\varepsilon_v(\alpha,d,v) = d\left(1576 - 17.6v + 0.00117v^3 + \frac{36067}{v^2}\right)\left(1+\alpha\left(1.43 + \frac{-0.916}{v} - 1\right)\right)$$

Where *a* is the load ratio and *v* is the speed in km/h and *d* the distance in km. The parameters entered in the previous function reflect a representative European truck. The speed is set according to the line haul facts: inter city, urban area…

And equivalent formula was adapted for railroad transportation. In this case, the main factor is the power generation choice for freight railroad. In this case electricity is chosen, as it is the power source for train in France on major routes. For half train operation the formula is:

$$\varepsilon_c(\alpha,d,v) = d\left(4.13\times10^{-4}v^2 + 63\right)\left(295 + 390\alpha\right)BSEF_{CO2} \times 0.0036$$

Where *a* is the load ratio *d* the distance in km, *v* is the speed in km/h and $BSEF_{CO2}$ the value for the brake specific emission function. Typically $BSEF_{CO2}$ is 17.6 10^{-6} g/J for France, 189.0 10^{-6} g/J for Germany and 127.4 10^{-6} g/J for the European average. Thus the emissions will greatly depend of the power station configuration at the country level (nuclear, hydro, coil…). These formulae can be easily extended to several means per linehauls and it turns out that the emissions functions are linear according to traveled distance and truckload, where the others variables are set according to the route.

4 RESULTS

4.1 Scenario 1: industrial competitors merge warehouses

The first case study came from the fact that most of the warehouses and plants for cosmetics, perfume and personal care are located in the same region, named Ile de France. Within a 60 km radius, centered in the northeast of Paris, 11 warehouses operated for this industry were founded. Extended product lines of high value products characterize this industry and therefore make it a perfect candidate as they use a lot of transportation means to serve their customers, i.e. the distribution centers located in the whole country. Eleven distribution centers were also numbered for the 2 retail chains, which gives 105 linehauls.

From now, each firm uses dedicated warehouses and transportation means independently from the others. As a result, the filling rate of truck even in the upstream of the supply chain is not very high despite an average distance to the distribution center of 413 km. So it seems that with their plants and the warehouses proximity plus the same type of product, these 11 supply chains are potentially good candidates for merging. The merging principle was to transfer all flows from plants to a single location, which will be the departure point for the 11 linehauls to the distribution centers.

The data was gathered and the deliveries were simulated with both cases: the current supply chains and the merged supply chain (as if integrated). The results of the two scenarii are summarized in table 3.

Scenario	Families	Distance (km)	Flow (pallet)	Deliveries	Truckload	CO2 (t)
Current SC 1.1	Care	2798 010	158950	6773	0.71	2730.3
Merged SC 1.2	Care	1990 700	158950	5135	0.94	2084.3
?	Variation	- 807 290 (-28.9%)	0	-1 638 (-24.2%)	0.23	- 646.0 (-23.6%)

Table 3: Results from case study 1 (annual basis by extrapolation)

The results show a great reduction in traveled distance coming mainly from a better truck filling and also from an improvement of the common facility location for several producers. As a consequence, the CO2 emissions dropped off 23%. This result could still be improved (-29% in CO2) by a full truckload policy, as most of the distribution center will now be served on a daily basis, and the others at least every two days, instead of once per week in average. As a positive side effect, even if it was not computed here, the amount of inventory held by the distribution centers is expected to decrease significantly.

4.2 Scenario 2: building volume up to transportation means substitution

The second case study is located within Rhône-Alpes region. In a radius of 48 km, centered in the east suburb of Lyon, 8 warehouses operated for the food industry was founded. Among others characteristics of these warehouses their was a difference in size from low to high volumes and also a great diversity of products coming from 22 different families. For the 2 retail chains, 35 distribution centers were served from the 8 warehouses with an average distance of 230 km. This case seems more challenging for the proximity merging principle.

As it was done in the previous case, the flows are concentrated on a single warehouse before shipping to the distribution centers.

The data was gathered and the deliveries were simulated with both cases: the current supply chains and the merged supply chain (as before). The results of the two scenarii are summarized in table 4.

Scenario	Families	Distance (km)	Flow (pallet)	Deliveries	Truckload	CO2 (t)
Current SC 2.1	Grocery	3 492 929	394 096	14 751	0.81	3 516.4
Merged SC 2.2	Grocery	2 955 484	394 096	12 814	0.93	3 088.8
?	Absolute (Variation)	- 537 445 (-15.4%)	0	- 1 937 (-13.1%)	0.12	- 427.6 (-12.2%)

Table 4: Results from case study 2 (annual basis by extrapolation)

As expected the economy in emissions are not at the same level than it was in the first case but it's still significant. A first source of improvement, from an environmental point of view, is to accept to not have the full benefit of upgraded frequency delivery due to freight consolidation and assign a full truckload policy at the departure of the warehouse, which leads to scenario 2.3.

But in this scenario some linehauls have high volumes that could make them eligible for train transportation. Railroads are not as convenient as truck linehauls, with mandatory transshipment and schedules, higher volume and long distance to be competitive. But from an CO2 emission point of view, trains are far more efficient than trucks above all when there are powered by hydroelectricity or nuclear electricity as it is mainly the case in France. The analysis of the data indicates that 3 line hauls have above 15 trucks / week flow a distance above 350km between WH and DC. Those truck line hauls would be candidate for railroad operations, with stand alone car or half train operations: sceanrio2.4.

Scenario	Modification from scenario 2.2	Distance (km)	Truckload	CO2 (t)
Merged SC 2.3	All trucks follow a full truckload policy	2 659 368	1.0	- 685.3 (-19.5%)
Merged SC 2.4	3 major linehauls transferred to railroad	2 369 287 903 203	Truck 0.92 Rail 0.97	- 951.5 (-26.0%)

Table 5: Alternate results from case study 2 (annual basis by extrapolation)

Compared to scenario 2.2, the scenario 2.3 shows an improvement in CO2 emissions by 7.3% and a delivery frequency drop by 6% in total. In fact, the frequency can drop by 50% on low volume routes, where a specific trade-off could be made between frequency and inventory. It has to be mentioned here that no customer encounters a drop in delivery frequency compare to scenario 2.1. On the other side, nearly no change occurred for the high volume customer.

In the case of scenario 2.4, the 3 major line hauls transferred to railroads represent 24% of the flow and are above 350 km to meet minimal distance requirement for traditional railroads operations. In terms of t.km these line hauls represent 35% of the total and show a direct added contribution to scenario 2.2 of 13.8% CO2 emission saved.

5 DISCUSSION

Until now, we focused on the gas emission reduction, as it is the main objective followed by this study, but there are also some side effects.

The first side effect relate to the economy of the solution. Even if it was not the first goal, it is noticeable that the operations will be more economic with the merged supply chains thanks to a better use of transportation means, which will also have positive consequences on handling with fewer shipments. In this article we don't pay more attention to cost and benefit share between the partners involved in such a supply chain. This may be seen as a limitation of this work, but we like to indicate that since the delivery frequency increased for all participants and the transportation cost dropped due to a better fill rate, the main issue will be the economic share between the participants rather than economical feasibility.

The second side effect is the variability reduction, even if the scenarios where not design to improve it. In fact as shown in table 6, as the flow goes up the relative variability of the flow is reduced. In return the reduction of variability will make train or barge operation more efficient and avoid urgent trucks to accommodate overshooting shipments.

Case	1		2	
Scenario	1.1	1.2	2.1	2.2
Operated linehauls	105	11	111	35
Mean flow / week	29.1	277.9	68.4	232.6
Standard deviation	56.3	318.9	120	350.9
Std dev. / mean	1.93	1.15	1.75	1.51

Table 6: Resulting flows variability

6 CONCLUSION

In this case study we demonstrate on real data from optimized supply chains that the vertical supply chain optimizations still leave room for horizontal collaboration. In this case the optimization was made according to an environmental objective. The supply chain merging principles indicated conduct the supply chain participants to share assets such as warehouse, distribution centers and transportation means and allows substitution of these means for more ecological ones. Of course, this of could be done with 3PL partners that allow more flexible network design changes and evolutions. The previous scenarios were done on the limited basis of the cases studies and still showed a 25% reduction in gas emissions with the new organization. But we like to point out that, as the number of firms or the number of product families will increased we can expect better gas emissions savings thanks to the bigger volumes.

As we are working with the actual supply chain data from the French retail chains, we worked on cases in order to validate de principles and their results. The results of the cases were presented to *Déméter* board members. They acknowledge the results and they look forward to have an experimentation based on these cases study and principles.

However, if from an environmental point of view, we founded that it is always interesting to merge supply chains, as long as the principles applied (i.e. enough flows to share and close from each other). More generally this problem, raise the question of the difference between the cost efficiency and emissions efficiency, that could be a future research.

On a more global supply chain point of view it could be interesting to search for the optimal solution of the many to many network design problem with an emission function and the application of the highlighted principles. This research now started could give some insight on the structure and the stakes of an ecologically optimized supply chain for retails chains at a country level.

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