Assessing the Environmental Benefits of Horizontal Cooperation in Logistics

Thomas Hacardiaux, Jean-Sébastien Tancrez

Louvain School of Management, CORE, UCL, Belgium

LOUVAIN School of Management

UCL Université catholique de Louvain

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Horizontal Cooperation

"An active cooperation between two or more firms that operate **on the same level** *of the supply chain and perform* **a comparable logistics function***". (Cruijssen et al., 2006)*

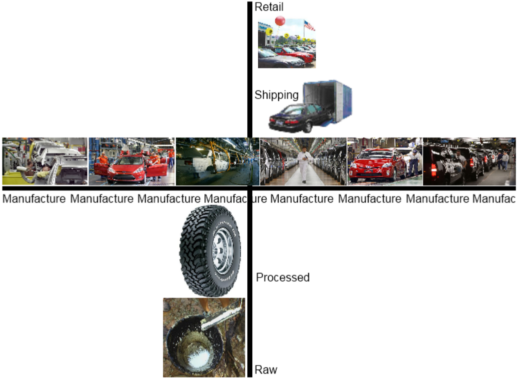


Figure: http://amh2020-0005.tumblr.com

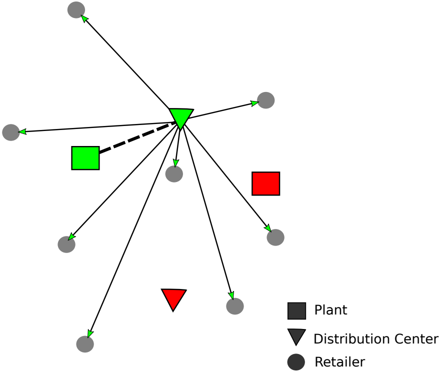
Current Situation

1. High potential CO_2 reduction related to transportation: vehicles are **loaded on average at 57%** of their capacity (Creemers et al., 2017).
2. Trend aiming at a **lower stock level** and a **higher delivery frequency** (Harris et al., 2011).
3. **High variation in the emission reductions** due to cooperation (i.e. between 8% and 33% in Soysal et al., 2018).

➠ **Our challenge:** present valuable **managerial insights** to help companies **assessing the potential environmental benefits** they can get when cooperating, **as a function of their characteristics.**

Benefit 1: Reduction of the Distances

1. Two companies with their own independent plants and **different products**.
2. Each company receives orders from retailers for its product.
3. The products of each companies **can be stored and delivered together**.



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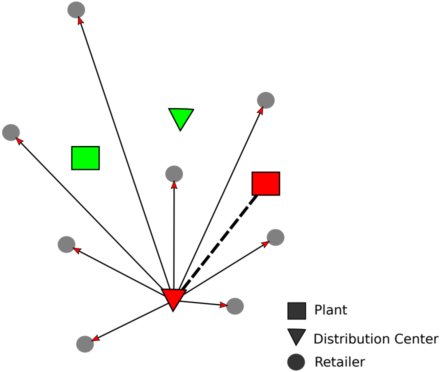

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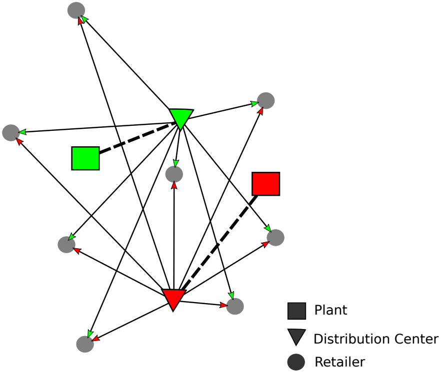

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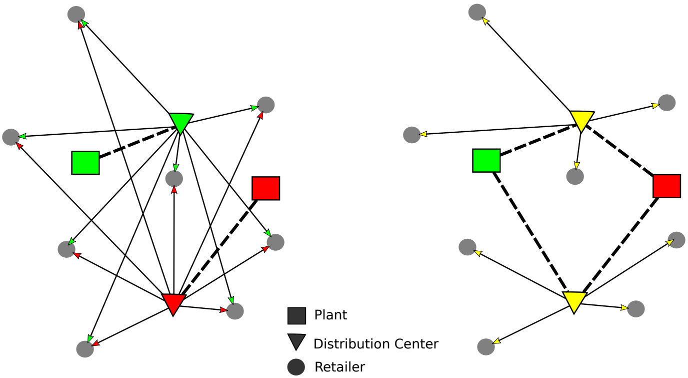
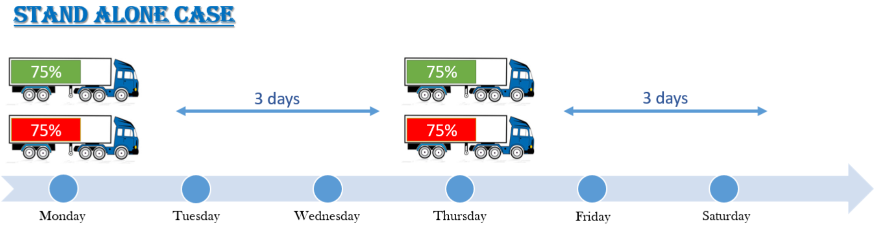


Benefit 2: Better Loading Rate



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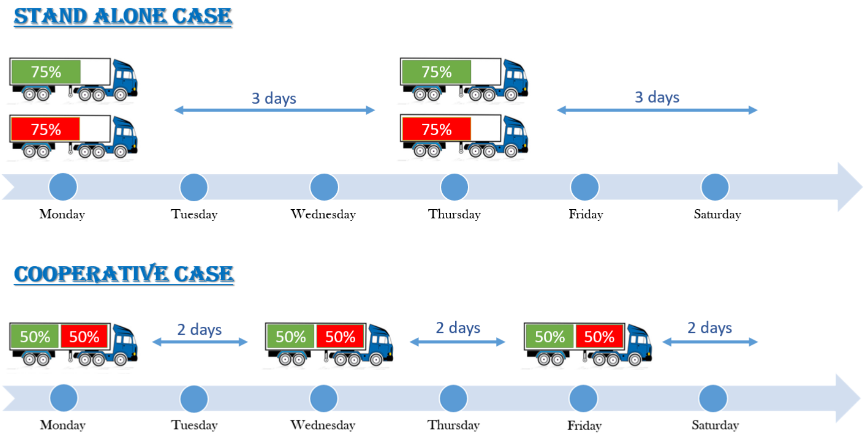

1. Higher delivery frequency.
2. Higher loading rate.
3. Lower number of vehicles/deliveries.

Location-Inventory Model

We use a **location-inventory model** to determine:

1. The number and the locations of the distribution centers.
2. The delivery network.
3. The inventory decisions.

When deciding on the **supply network design**, the focus is given on **cost reduction**.

Companies are interested in **the assessment of the possible CO_2 emissions reductions** as an additional **motivation to cooperate** horizontally.

Location Inventory Model

We aim at **minimizing the total cost** composed of transportation, cycle inventory, ordering, facility opening and safety stock costs.

$$
\begin{aligned}
Min \quad & \sum_{d,r} O_{dr} \frac{\Lambda_r}{Q_{dr}} y_{dr} + \sum_{d,r,i} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r} y_{dr} + \sum_{d,i} \sqrt{2\, K_d^i\, H_d^i}\, v_{1d}^i \\
& + \sum_{d} F_d\, y_d + \sum_{d,i} H_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i + \sum_{d,r,i} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, y_{dr} \\
s.t. \quad & \sum_r \lambda_r^i\, (y_{dr})^2 \le (v_{1d}^i)^2 \qquad \forall d, i \\
& \sum_r (\sigma_r^i)^2\, (y_{dr})^2 \le (v_{2d}^i)^2 \qquad \forall d, i \\
& \sum_d y_{dr} = 1 \qquad \forall r \\
& y_{dr} \le y_d \qquad \forall d, r \\
& v_{1d}^i, v_{2d}^i \ge 0 \qquad \forall d, i \\
& y_{dr}, y_d \in \{0, 1\} \qquad \forall d, r
\end{aligned}
$$

Experiments

Our research proceeds in **3 steps**.

1. Designing the supply chain networks of the companies when they are independent.
2. Designing the supply chain networks when they collaborate.
3. Comparing CO_2 emissions between the total emissions in the stand alone cases and the emissions in the cooperation case.

As our model provides the traveled distances and the loading rate of the vehicles (shipment sizes), it allows to apply the $\boldsymbol{CO_2}$ **emissions computation** proposed by Pan et al. (2013).

$$\epsilon^{v}_{dr} = \epsilon^{ve}\frac{\Lambda_r}{Q_{dr}} + (\epsilon^{vf} - \epsilon^{ve})\frac{\Lambda_r}{C_{dr}}$$

➠ If the carried quantity doubles, the emissions **less than double**.

Parameter Combinations

Network Parameters	
$n_r = n_d$	60
Width	(500, 1000) km
Capacity Percentages	(10, 20, 30, 40, 50, 60, 70, 80, 90, 100)
Demand Parameters	
Λ_r	$\in$ [50, 250] items/week
CV	(0.4, 0.7, 1)
α	97,5%
z^i_α	1,96
Cost Parameters	
F_d	(1000, 2000, 4000) €/week
K^i_d	(250, 500, 1000) €/order
$H^i_d = H^i_r$	(0.25, 0.50, 1) €/item·week

A total of **24,300 experiments** is performed in our analysis.

1. 1620 parameter combinations $(2 \cdot 10 \cdot 3 \cdot 3 \cdot 3 \cdot 3)$.
2. Five maps are generated resulting in 8100 instances.
3. We run the model three times: when companies are independent (2 cases) and when they decide to cooperate.
4. Average optimality gap 0.25% - limited to 1800 seconds.

CO_2 Emissions Reductions

CV	H	Width = 500			Width = 1000			Average
		F_d=1000	F_d=2000	F_d=4000	F_d=1000	F_d=2000	F_d=4000	(all cases)
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0.4	0.5	18.0% 3.17|2.08 0.80|0.90	14.2% 2.05|1.30 0.82|0.92	7.2% 2.00|1.01 0.82|0.93	17.2% 5.65|3.59 0.76|0.88	24.2% 2.58|2.08 0.79|0.88	11.2% 2.00|1.17 0.81|0.93	15.3% 2.91|1.87 0.80|0.91
0.4	1	18.2% 4.15|2.65 0.79|0.90	19.9% 2.32|1.69 0.82|0.91	9.7% 2.00|1.11 0.82|0.93	14.2% 7.19|4.12 0.78|0.90	24.7% 4.01|2.88 0.77|0.87	19.7% 2.06|1.56 0.82|0.90	17.7% 3.62|2.33 0.80|0.90
1	0.25	20.3% 2.33|1.71 0.81|0.90	9.7% 2.00|1.11 0.82|0.93	6.8% 2.00|1.00 0.82|0.93	24.2% 4.08|2.90 0.76|0.86	19.6% 2.08|1.57 0.81|0.90	7.1% 2.00|1.01 0.81|0.93	14.6% 2.41|1.55 0.80|0.91
1	0.5	18.9% 3.40|2.26 0.79|0.90	15.9% 2.05|1.37 0.82|0.92	7.5% 2.00|1.03 0.82|0.93	18.7% 6.04|3.67 0.76|0.87	**25.2%** 2.76|2.23 0.79|0.87	12.3% 2.00|1.21 0.81|0.92	16.4% 3.04|1.96 0.80|0.90
1	1	17.1% 4.63|2.87 0.78|0.90	21.2% 2.43|1.81 0.81|0.90	11.3% 2.00|1.17 0.82|0.93	14.8% 7.39|4.29 0.78|0.90	24.4% 4.46|3.11 0.76|0.86	21.7% 2.11|1.68 0.82|0.89	18.4% 3.84|2.49 0.80|0.90
Average (all cases)		18.7% 3.32|2.20 0.80|0.90	15.1% 2.14|1.40 0.82|0.92	8.2% 2.00|1.05 0.82|0.93	19.0% 5.69|3.55 0.77|0.88	22.8% 2.99|2.23 0.79|0.88	13.0% 2.03|1.27 0.82|0.92	**16.1%** **3.03|1.95** **0.80|0.90**

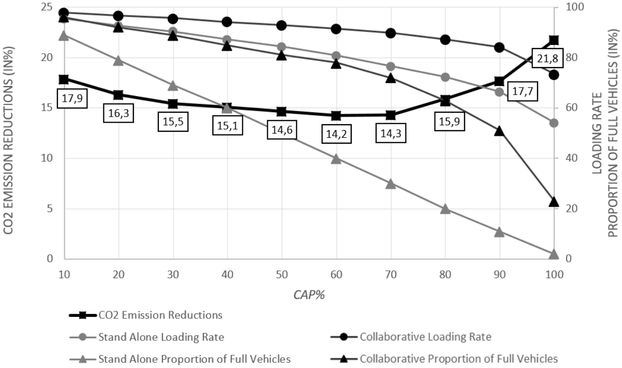
Managerial Insights

CV H	Width = 500			Width = 1000			Average
	F_d=1000	F_d=2000	F_d=4000	F_d=1000	F_d=2000	F_d=4000	(all cases)
Average (all cases)	18.7%	15.1%	8.2%	19.0%	22.8%	13.0%	**16.1%**
	3.32|2.20	2.14|1.40	2.00|1.05	5.69|3.55	2.99|2.23	2.03|1.27	**3.03|1.95**
	0.80|0.90	0.82|0.92	0.82|0.93	0.77|0.88	0.79|0.88	0.82|0.92	**0.80|0.90**

➠ The reduction in CO_2 emissions comes from **two main factors**:

1. Sharing their distribution centers reduces the average **distance** (average accounting for the delivery frequency) **to the retailers by 36.8%**.
2. Sharing vehicles improves the average **vehicle loading rate by 10%**, and leads to a reduction in the total **number of trips per period by 12.5%** on average.

Managerial Insights



➠ When the capacity increases, the CO_2 emissions reductions **first decrease and then increase**.

1. When the **capacity is low**, more DCs are opened so the cooperation allows important savings in traveled kilometers.
2. When the **capacity is high**, horizontal cooperation is particularly beneficial as it improves the loading rate.

Managerial Insights

➠ **A larger partnership** has a positive impact on the CO_2 emissions but the marginal benefit decreases with each newcomer.

		Stand Alone Case				Cooperative Case			
	CO_2 Reduc.	CO_2	Trips	DCs	LR	CO_2	Trips	DCs	LR
2 Partners	19.3%	18044	59.3	3.7	77%	14555	52.3	2.4	88%
	9.4%	+51.2%	+30.2	+1.9	+1%	+33.6%	+22.4	+0.5	+5%
3 Partners	28.7%	27278	89.5	5.6	78%	19444	74.7	2.9	93%
	5.1%	+32.8%	+29.1	+1.9	+0%	+23.3%	+21.9	+0.3	+2%
4 Partners	33.8%	36231	118.6	7.5	78%	23975	96.6	3.2	95%

Managerial Insights

➠ **A larger partnership** has a positive impact on the CO_2 emissions but the marginal benefit decreases with each newcomer.

		Stand Alone Case				*Cooperative Case*			
	CO_2 *Reduc.*	CO_2	*Trips*	*DCs*	*LR*	CO_2	*Trips*	*DCs*	*LR*
2 Partners	19.3%	18044	59.3	3.7	77%	14555	52.3	2.4	**88%**
	+9.4%	+51.2%	+30.2	+1.9	+1%	+33.6%	+22.4	+0.5	+5%
3 Partners	28.7%	27278	89.5	5.6	78%	19444	74.7	2.9	**93%**
	+5.1%	+32.8%	+29.1	+1.9	+0%	+23.3%	+21.9	+0.3	+2%
4 Partners	33.8%	36231	118.6	7.5	78%	23975	96.6	3.2	**95%**

1. **Improve the loading of the vehicles**, reducing the CO_2 emissions related to the number of trips per period.

Managerial Insights

➠ **A larger partnership** has a positive impact on the CO_2 emissions but the marginal benefit decreases with each newcomer.

		Stand Alone Case				*Cooperative Case*			
	CO_2 *Reduc.*	CO_2	*Trips*	*DCs*	*LR*	CO_2	*Trips*	*DCs*	*LR*
2 Partners	19.3%	18044	59.3	3.7	77%	14555	52.3	**2.4**	88%
	+9.4%	+51.2%	+30.2	+1.9	+1%	+33.6%	+22.4	+0.5	+5%
3 Partners	28.7%	27278	89.5	5.6	78%	19444	74.7	**2.9**	93%
	+5.1%	+32.8%	+29.1	+1.9	+0%	+23.3%	+21.9	+0.3	+2%
4 Partners	33.8%	36231	118.6	7.5	78%	23975	96.6	**3.2**	95%

1. **Improve the loading of the vehicles**, reducing the CO_2 emissions related to the number of trips per period.
2. **Open more distribution centers** for which they share the opening costs, reducing the distances with the retailers.

Managerial Insights

Comparison	F_d 1000|4000	$Cap\%$ 10|100	K_d 250|1000	$H_d^i = H_r^i$ 0.25|1	$Width$ 500|1000	CV 0.4|1	$\#Partners$ 2|4
CO2 Emissions	-8.2%	+3.9%	-5.5%	+3.6%	+3.9%	+0.7%	+14.5%
Logistic Cost	+3.5%	+7.1%	-3.1%	-3.1%	+0.5%	-1.2%	+13.4%

➠ The horizontal cooperation is more environmentally profitable if:

1. Low facility opening costs;
2. Unsuited vehicle capacity;
3. Low order costs;
4. Expensive products;
5. Vast market;
6. High demand variability;
7. High number of partners.

Conclusion

➠ Partnerships with more than two partners, with low order costs, using vehicles with a large capacity and delivering their products on a vast market have to be encouraged as **they are profitable on both dimensions**.

➠ The horizontal cooperation **reduces CO_2 emissions** for companies with cheap facility opening costs delivering expensive products on a market with a large variability **but increases the costs**.

➠ **To conclude**, the horizontal cooperation allows **a reduction of the CO_2 emissions of 16%** in average. But this result varies with the partners and markets characteristics.

Future researches:

1. Other environmental index than CO_2 emissions.
2. Find the best trade off: costs / CO_2 emissions reductions.

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Main References

$$Q_{dr} = min\left(C_{dr}, \sqrt{\frac{2\,O_{dr}\,\Lambda_r}{\sum_i H_r^i \frac{\lambda_r^i}{\Lambda_r}}}\right) \quad \forall d, r$$

The percentage can be translated as the theoretical percentage of retailers which are not constrain by the vehicle's capacity.

1. We begin by running the model without capacities for both companies. We obtain 120 optimal shipment sizes, Q^i_{dr}.
2. Values for retailers which are at the same location as opened DCs are removed and we rank the remaining values in ascending order.
3. We take the n-th value corresponding to the different percentages.
4. We restart the calculation when parameters change.