"Accounting for individual partners preferences in horizontal cooperation"

Hacardiaux, Thomas ; Defryn Christof ; Tancrez, Jean-Sébastien ; Lotte Verdonck

ABSTRACT

Horizontal cooperation in logistics has gathered momentum in the last decade as a way to reach economic as well as environmental benefits. In the literature, these benefits are most often assessed through aggregation of demand and supply chain optimization of the partnership as a whole. However, such an approach ignores the individual preferences of the participating companies and forces them to agree on a unique coalition objective. Companies with different (potentially conflicting) preferences could improve their individual outcome by diverging from this joint solution. To account for companies preferences, we propose an optimization framework that integrates the individual partners' interests directly in a cooperative model. The partners specify their preferences regarding the decrease of logistical costs versus reduced CO2 emissions. Doing so, all stakeholders are more likely to accept the solution, and the long-term viability of the collaboration is improved. First, we formulate...

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Accounting for individual partners preferences in horizontal cooperation

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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)*

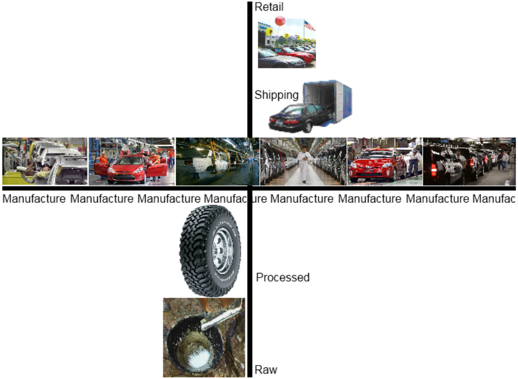
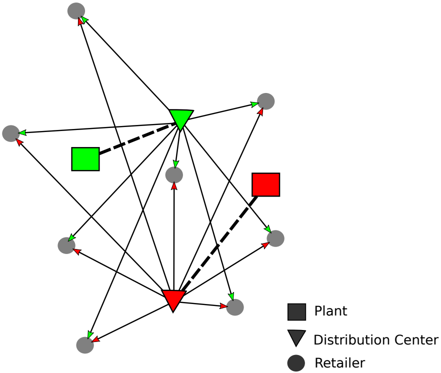


Figure: http://amh2020-0005.tumblr.com

Benefit 1: Reduction of the Distances

1. Two companies with their own independent plants and **different products**.
2. The products of each companies **can be stored and delivered together**.
3. **Cost and CO_2 emissions** reductions.



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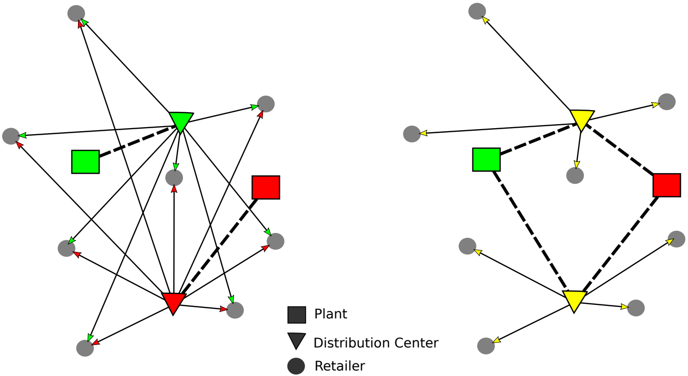
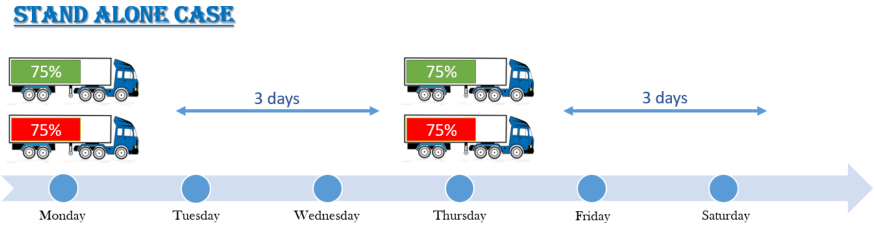


Benefit 2: Better Loading Rate



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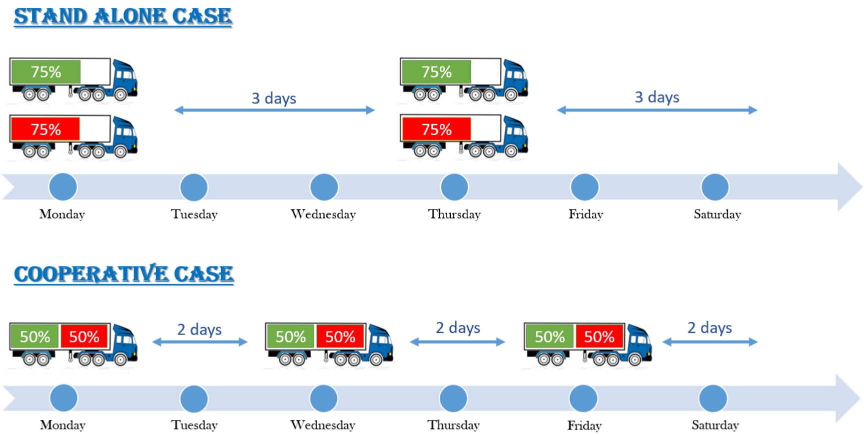

1. Higher delivery frequency - lower cost.
2. Higher loading rate.
3. Lower number of deliveries - CO_2 emissions reductions.

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).

➠ **First challenge:** present a bi-objective (logistics cost and CO_2 emissions) inventory-location model with horizontal cooperation.

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).

➠ **First challenge:** present a bi-objective (logistics cost and CO_2 emissions) inventory-location model with horizontal cooperation.

1. **Mismatch** between individual partner and coalition objectives.
2. Decrease **the willingness to leave** the cooperation.

➠ **Second challenge:** integrate the individual sensibility to the reduction of each objective for each partner and their influence in the cooperation.

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.

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

➠ We aim at **minimizing the CO_2 emissions** emitted during the transportation.

...for each partner !

Objectives Opposition

Two ways to reduce the CO_2 emissions:

1. Decrease the traveled distances.
2. Improve the loading rate (lower number of trips).

Consequences:

1. Open more DCs thus higher opening cost.
2. Increase the average stock level thus higher inventory costs.

➠ This emphasizes the importance of **balancing costs and CO_2 emissions**.

Location-Inventory Model

We aim at **minimizing the total cost and the CO_2 emissions**.

$$\min \quad \frac{\Lambda^i}{\Lambda} \sum_d F\, y_d + \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d T\, D_{dr} \frac{\Lambda_r}{Q_{dr}} x_{dr} + \sum_{d,r} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r} x_{dr}$$

$$+ \sum_d \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i + \sum_{d,r} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_d h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i \qquad \forall i$$

$$\min \quad \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d \left[\epsilon^e \frac{\Lambda_r}{Q_{dr}} + (\epsilon^f - \epsilon^e) \frac{\Lambda_r}{C}\right] D_{dr}\, x_{dr} \qquad \forall i$$

$$s.t. \quad \sum_r \lambda_r^i\, (x_{dr})^2 \leq (v_{1d}^i)^2 \qquad \forall d, i$$

$$\sum_r (\sigma_r^i)^2\, (x_{dr})^2 \leq (v_{2d}^i)^2 \qquad \forall d, i$$

$$\sum_d x_{dr} = 1 \qquad \forall r$$

$$x_{dr} \leq y_d \qquad \forall d, r$$

$$v_{1d}^i, v_{2d}^i \geq 0 \qquad \forall d, i$$

$$x_{dr}, y_d \in \{0, 1\} \qquad \forall d, r$$

Two approaches resulting in Pareto fronts

$$\min \quad \frac{\Lambda^i}{\Lambda} \sum_d F\, y_d + \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d T\, D_{dr}\, \frac{\Lambda_r}{Q_{dr}}\, x_{dr} + \sum_{d,r} H_r^i\, \frac{Q_{dr}}{2}\, \frac{\lambda_r^i}{\Lambda_r}\, x_{dr} + \sum_d \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i$$

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$$\min \quad \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d \left[\epsilon^e \frac{\Lambda_r}{Q_{dr}} + (\epsilon^f - \epsilon^e)\frac{\Lambda_r}{C}\right] D_{dr}\; x_{dr} \qquad \forall i$$

➠ **Approach 1: Articulation at the coalition level**

$$\min \quad \sum_d F\, y_d + \sum_{d,r} T\, D_{dr} \frac{\Lambda_r}{Q_{dr}} x_{dr} + \sum_{d,r,i} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r} x_{dr} + \sum_{d,i} \sqrt{2\, K_d^i\, h_d^i}\, v_{1d}^i$$

$$+ \sum_{d,r,i} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_{d,i} h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i$$

$$\min \quad \sum_{d,r} \left[\epsilon^e \frac{\Lambda_r}{Q_{dr}} + (\epsilon^f - \epsilon^e)\frac{\Lambda_r}{C}\right] D_{dr}\; x_{dr}$$

Weighted sum program

The pareto front of optimal solutions balancing logistics cost and CO_2 emissions can be computed using a **multi-objective exact method** as the weighted sum approach.

$$U = \sum_{i=1}^{k} W_i \, F_i(x)$$

Weights are chosen such that $\sum_{i=1}^{k} W_i = 1$ with $W \geq 0$.

➠ As costs-emissions preference is used in the shipment size decision computed a priori, other multi-objective methods are difficult to use.

$$Q_{dr} = min \left(C, \sqrt{\frac{\sum_i 2 \, (T + \beta \, \epsilon^e) \, D_{dr} \, \Lambda_r}{\sum_i H_r^i \, \lambda_r^i / \Lambda_r}} \right)$$

Companies individuality

1. Companies are **autonomous in the decision-making.**
2. They have their **own expectations** about the benefits related to the collaboration.

➠ We use a costs-emissions weight β^i for the individual preferences.

"β^i reveals how important its cost reduction is compared to its CO_2 emissions reduction, for a partner i."

➠ β^i can be stated from the stand-alone case.

Two approaches resulting in Pareto fronts

$$\min \quad \frac{\Lambda^i}{\Lambda} \sum_d F\, y_d + \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d T\, D_{dr} \frac{\Lambda_r}{Q_{dr}} x_{dr} + \sum_{d,r} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r} x_{dr} + \sum_d \sqrt{2\, K_d^i\, h_d^i\, v_{1d}^i}$$

$$+ \sum_{d,r} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_d h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i \qquad \forall \boldsymbol{i}$$

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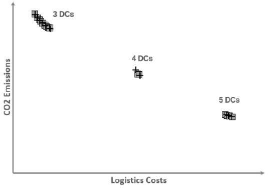
➠ **Approach 2: Articulation at the partner level**

$$min \quad \frac{\Lambda^i}{\Lambda} \sum_d F\, y_d + \sum_{d,r} T\, D_{dr} \frac{\lambda_r^i}{Q_{dr}} x_{dr} + \sum_{d,r} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r} x_{dr} + \sum_d \sqrt{2\, K_d^i\, h_d^i\, v_{1d}^i}$$

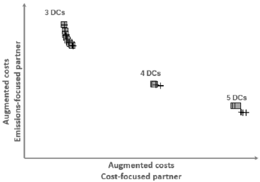
$$+ \sum_{d,r} H_r^i\, z_\alpha^i\, \sigma_r^i \sqrt{LT_{dr}}\, x_{dr} + \sum_d h_d^i\, z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i + \boldsymbol{\beta^i} \sum_{d,r} \left[\epsilon^e \frac{\lambda_r^i}{Q_{dr}} + (\epsilon^f - \epsilon^e) \frac{\lambda_r^i}{C}\right] D_{dr}\, x_{dr}$$

$$\forall \boldsymbol{i}$$

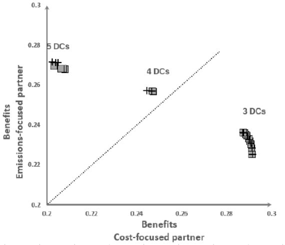
Pareto fronts analysis



(a) Total coalition costs versus total coalition CO_2 emissions.



(b) Augmented costs for both partners.



(c) Relative benefits in augmented costs from cooperating, for both partners.

Pareto fronts obtained using the articulation at the coalition level (□) and the articulation at the partner level (+) for companies with different preferences.

Identifying unique solutions

Three approaches to highlight a solution

1) Preference articulation at coalition level

Transform the individual preferences (β^i) into a collaborative weight (β) based on the volumes or the augmented costs of partners.

2) Preference articulation at individual level

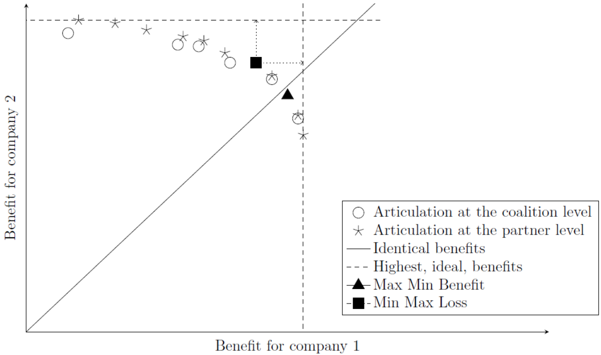
Generate partner's influence weight γ^i which characterize the influence of the companies on the final cooperative solution. To define them, we rely again on demand volumes or the stand-alone augmented costs.

Identifying unique solutions

3) Partners benefits approach

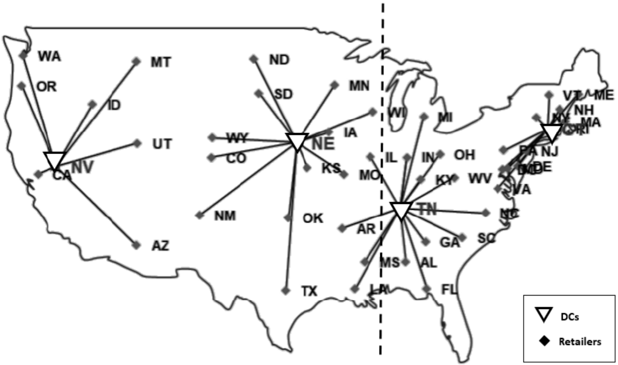
Look at the benefits that cooperation generates for the partners individually.

1. Maximizing the minimal partner benefit.
2. Minimizing the maximal partner loss

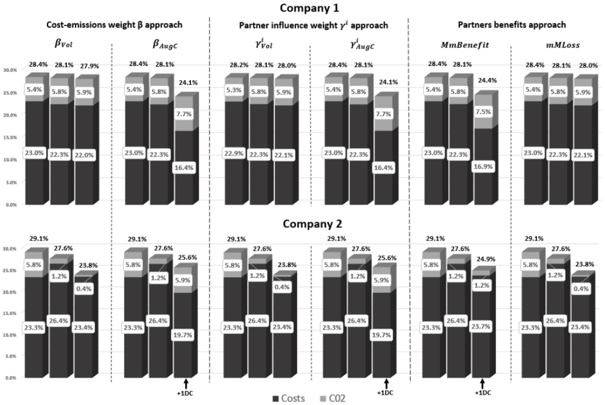


Experimental setting

We focus on a cooperation between **two companies**. The retailer's locations are taken from the **49-node data** set by Daskin (2011) (48 continental U.S. state capitals + Washington DC). Retailers' locations are considered to be the **possible locations for the DCs**.



Different individual costs-emissions preferences



1. The **cost-focused company also benefits significantly** from the reduction in CO_2 emissions.
2. The opportunities for **decreasing the emissions** for company 2 when collaborating is **limited**.
3. Methods lead to **dissimilar solutions**.

Conclusion

➠ Current research considers horizontal logistics collaboration as a **single-objective minimization** of transportation costs, assuming partners agree on **a unique collaborative goal**.

➠ We propose a **multi-objective** and **multi-partner** model including the **individual costs-emissions preferences** and the partners' influence weight in the collaboration.

➠ Collaboration **remains beneficial** for both partners in all cases.

➠ However, preference weight combinations **impact the individual benefits levels** of the partners.

➠ When partners' preferences are different, each company **benefits more from** a reduction of **its non-priority objective**.

Future research:

1. Include more complex allocation techniques.
2. Apply these approaches to other cooperation configurations.

Main References

1. Defryn, C., Sorensen, K., and Dullaert, W. (2019). Integrating partner objectives in horizontal logistics optimisation models. Omega, 82, 1-12.
2. Hacardiaux, T., Tancrez, J. S. (2019). Assessing the environmental benefits of horizontal cooperation using a location-inventory model. Central European Journal of OperatHions Research, 1-25.
3. Atamturk, A., Berenguer, G., and Shen, Z-L. (2012). A conic integer programming approach to stochastic joint location-inventory problems. Operations Research, 60(2): 366-381.
4. Comas Marti, J. M., Tancrez, J.-S., and Seifert, R. W. (2015). Carbon footprint and responsiveness trade-offs in supply chain network design. International Journal of Production Economics, 166:129-142.
5. Creemers, S., Woumans, G., Boute, R., and Beliën, J. (2017). Tri-vizor uses an efficient algorithm to identify collaborative shipping opportunities. Interfaces, 47(3):244-259.
6. Cruijssen, F. (2006). Horizontal cooperation in transport and logistics. Thesis. CentER, Tilburg University.
7. Cuervo, D.P., Vanovermeire, C., and Sorensen, K. (2016). Determining collaborative profits in coalitions formed by two partners with varying characteristics. Transportation Research Part C: Emerging Technologies.
8. Harris, I., Naim, M., Palmer, A., Potter, A., and Mumford, C. (2011). Assessing the impact of cost optimization based on infrastructure modeling on CO2 emissions. International Journal of Production Economics, 131(1):313-321.
9. Pan, S., Ballot, E., and Fontane, F. (2013). The reduction of greenhouse gas emissions from freight transport by pooling supply chains. International Journal of Production Economics, 143(1):86-94.
10. Schuster Puga, M. and Tancrez, J.-S. (2017). A heuristic algorithm for solving large location-inventory problems with demand uncertainty. European Journal of Operational Research, 259(2):413-423.

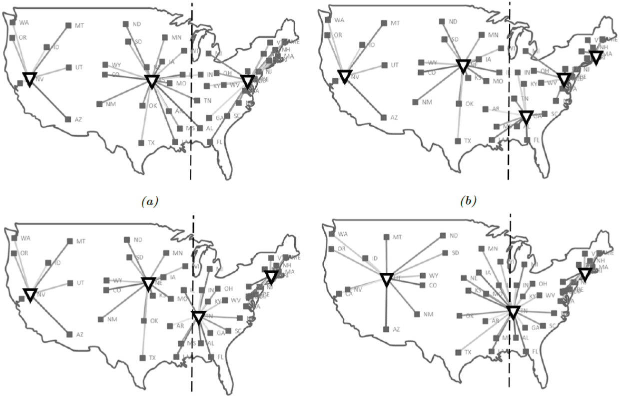
Companies with different sizes

The first company is twice the size of the second company.

	$\beta^1/\beta^2 = 3/3$			$\beta^1/\beta^2 = 1/5$			$\beta^1/\beta^2 = 5/1$		
	Coop.	Large C1	Small C2	Coop.	Large C1	Small C2	Coop.	Large C1	Small C2
Augm. costs	-26.8*	-16.8	-40.5	-26.6*	-16.5	-37.6	-22.8*	-16.2	-37.1
Logistics costs	-26.5	-16.3	-40.3	-32.3	-13.0	-52.3	-26.3	-21.5	-33.9
CO_2 emissions	-27.2	-17.7	-40.8	-24.3	-30.7	-6.6	-30.8	-7.2	-54.1

1. The relative benefits of both partners are **very different**.
2. The **large partner** already has a more effective supply network before cooperating, thanks to better **economies of scale**.
3. The **small company**, when cooperating, gets access to a larger number of DCs , better filled trucks (from 79% to 96%) and more frequent deliveries.
4. Note that each company **benefits most in the non-priority objective**.

Different geographical demand distribution



(a) (b) (c) (d)

➠ When geographical spread and individual preferences differ, applying **approaches that conserve these individual preferences** allows to design a network with **different priorities** in the regions.