Evaluation of the potential impacts of off-hour deliveries

INTRODUCTION

In recent years, there has been a growing awareness among city stakeholders (public and private) of the need to act on urban goods movement (UGM) in order to reduce the negative effects of transport. But this action should not impact economic vitality. This challenge mobilizes the reflection of researchers and experts in urban logistics around the search for solutions to achieve this.

Off-hour Deliveries (OHD) could be one of those solutions. The principle consists in postponing deliveries to periods when urban traffic is less dense, outside peak passenger traffic periods. The expected effects of the adoption of OHDs, in terms of environmental impacts, stem from the assumption that carrying out a share of goods movements during periods of low infrastructure demand, and therefore lower congestion, improves urban traffic conditions in general and particularly freight traffic conditions. As goods movements take place under better traffic conditions, several chain effects should be observed: reduction of travel times, reduction of energy consumption, reduction of GHG and pollutant emissions, reduction of accidents, reduction of inconvenient parking, etc.

Several OHD experiments have been conducted in cities around the world (Bertazzo et al., 2016; Delaître, 2010; Holguín-Veras et al., 2016; Niches, 2006; STRAIGHTSOL, 2014). These experiments, conducted at different scales, but mostly at small scale, lead to promising results. However, they raise the question of whether they can be efficient to reduce emissions in a context of large-scale deployment of OHDs, since general traffic conditions will be affected. The purpose of this paper is to answer the following questions: does postponing a large share of goods movements during the off-hours (OH) leads to a significant reduction of pollutant emissions? Could this justify the economic and organizational changes that such a postponement would cause, while we know that these changes have a cost for all the actors involved in UGM? The answers to these questions would help to better guide the decision-making of the actors involved in UGM.

A scenario-based simulation relating to the LUA is used to accurately evaluate the potential of OHDs to reduce emissions generated by UGM. It contributes to extend the short body of literature on the impacts of OHDs deployment at large scale.

METHODS

This section includes the methodological framework description and the main characteristics of the study area through the presentation of data.

Description of the methodological framework

The assessment of the potential impact of OHDs is based on a four steps methodology represented by

Figure *1*.

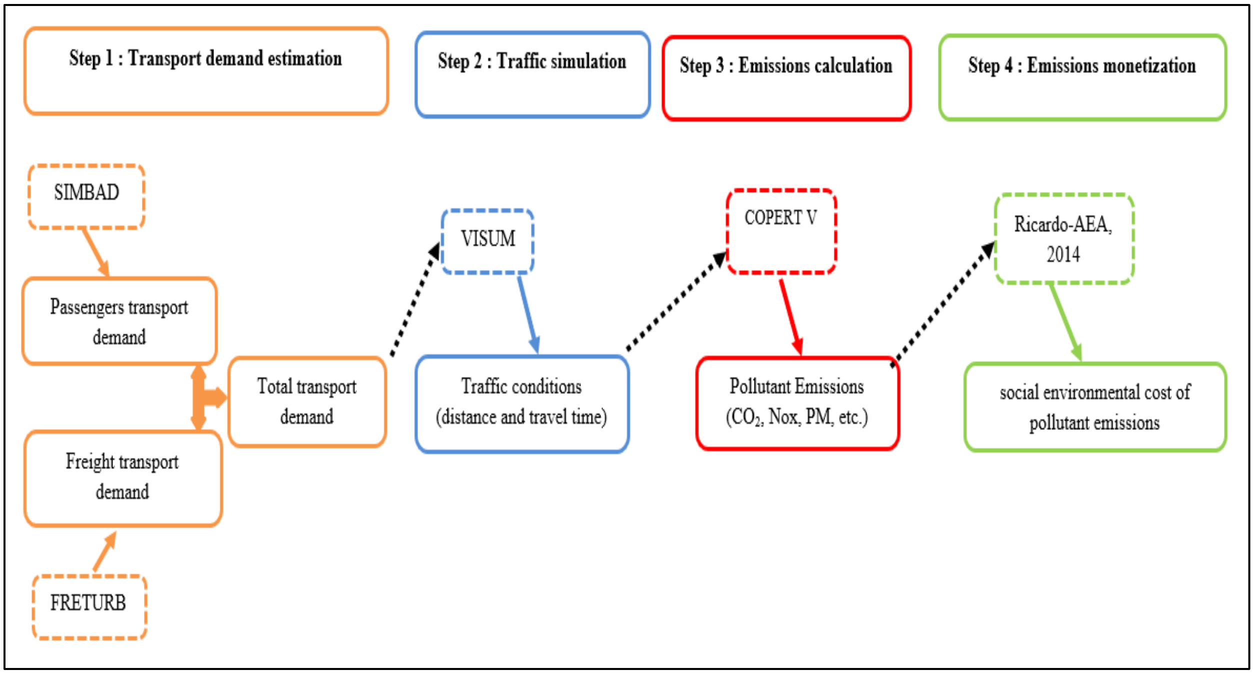


Figure 1. Methodological framework

Step 1 Transport demand estimation

Our case study is the LUA within its 1999 limits. It is divided in 777 IRIS (the smallest statistical unit in France) which are here the origin and destination areas of passenger and freight flows. In order to generate origin-destination (OD) matrices representing the total transport demand of the LUA, we use two tools developed by researchers from the Laboratoire Aménagement Economie Transports (LAET): SIMBAD (Nicolas et al., 2009) and FRETURB (Routhier and Toilier, 2007). They respectively provide OD matrices for passenger and freight movements. The OD matrix of the total traffic is obtained by aggregating the two OD matrices. It is not our aim to explain in detail the methodology of the two tools, readers can refer to the papers mentioned below to have more information.

Step 2 Traffic simulation

The simulation of traffic conditions (travelled distance / travel time) is done with VISUM. Based on 2015 EMD Lyon data, four homogeneous periods are considered : morning peak hour HPAM (7-9 am) ; afternoon peak hour HPPM (5-7 pm) ; daytime off-hours HCJ (9 am -5 pm and 7-9 pm) ; Night (9 pm-7 am), corresponding to Off-hours.

In addition to current situation (“*Scen ref*”), five scenarios are built in order to capture the effect of postponing deliveries from day to night : Scen 20%, Scen 50%, Scen 80%, Scen 100%, and Scen 0%.

Step 3 Emissions calculation

We calculate GHG and pollutant emissions based on COPERT V emission standards (Ntziachristos et al., 2009) for goods transport vehicles. Our estimation considers a typical fleet of trucks and vans based on the 2012 French National Fleet Surveys, and the Copcete tool (Coulombel et al., 2018).

Step 4 Emissions monetization

Pollutant emissions are translated into monetary terms from the European guideline on external transport costs (Ricardo-AEA, 2014).

Data

Assuming that OHDs can have different impacts from one area to another, depending on their density, we divided the AUL into four rings (C1 to C4) according to the IRIS population densities around the city centre of Lyon (see **Erreur ! Source du renvoi introuvable.**).

Table 1. Characteristic data of Lyon urban area

	Socio-economic data						
	AUL	**C1**	**C2**	**C3**	**C4**	**C1 - LUA**	**LUA - C1**
Inhabitants (1000)	1,916.1	704.2	351.6	249.9	610.4	-	-
		36.8%	18.3%	13.0%	31.9%	-	-
Area (km²)	3,325	73.3	129.7	253.5	2,868.5	-	-
		2.2%	3.9%	7.6%	86.3%	-	-
Inhab/km²	576.3	9,612.2	2,711.6	985.8	212.8	-	-
Jobs (1000)	1,267.1	562.3	207.4	182.0	315.5	-	-
		44.4%	16.4%	14.4%	24.9%	-	-
Jobs/km²	381.1	7,674.9	1,599.2	717.9	110	-	-
Establishments (1000)	275.7	117.3	41.9	36.7	79.7	-	-
		42.5%	15.2%	13.3%	28.9%	-	-
(Job/Estab)	4.6	4.8	4.9	5.0	4.0	-	-
	Daily distribution of trips by ring and vehicle type (1,000)						
PC	719.3	135.4	48.9	36.7	188.5	79.4	86.5
		18.8%	6.8%	5.1%	26.2%	11.0%	12.0%
LCV	119.9	27. 6	5.6	4.3	18.5	19.1	19.1
		23.0%	4.7%	3.6%	15.5%	15.9%	15.9%
Rigid HGV	74.9	14.6	35.8	3.3	13.3	11.3	11.3
		19.5%	4.8%	4.5%	17.8%	15.1%	15.1%
Articulated HGV	24.7	2.0	0.7	0.5	2.4	6.2	6.2
		8.3%	2.9%	2.0%	9.9%	25.3%	25.3%
Total (PCE)	1,110.8	211.1	66. 3	51.1	249.1	146.2	153.3
		19.0%	6.0%	4.6%	22.4%	13.2%	13.8%

RESULTS

Freight traffic emissions: the whole of the LUA

In the current situation (Scen Ref) the LUA UGM generates 382,778 t of CO_2, 195 t of CO, 2,462 t of NOx, 8 t of PM and 20 t of VOC per year (see **Table 2**). OHDs lead to a reduction in pollutant emissions as the percentage of postponed flows increases.

Table 2. CO_2 and pollutant emissions

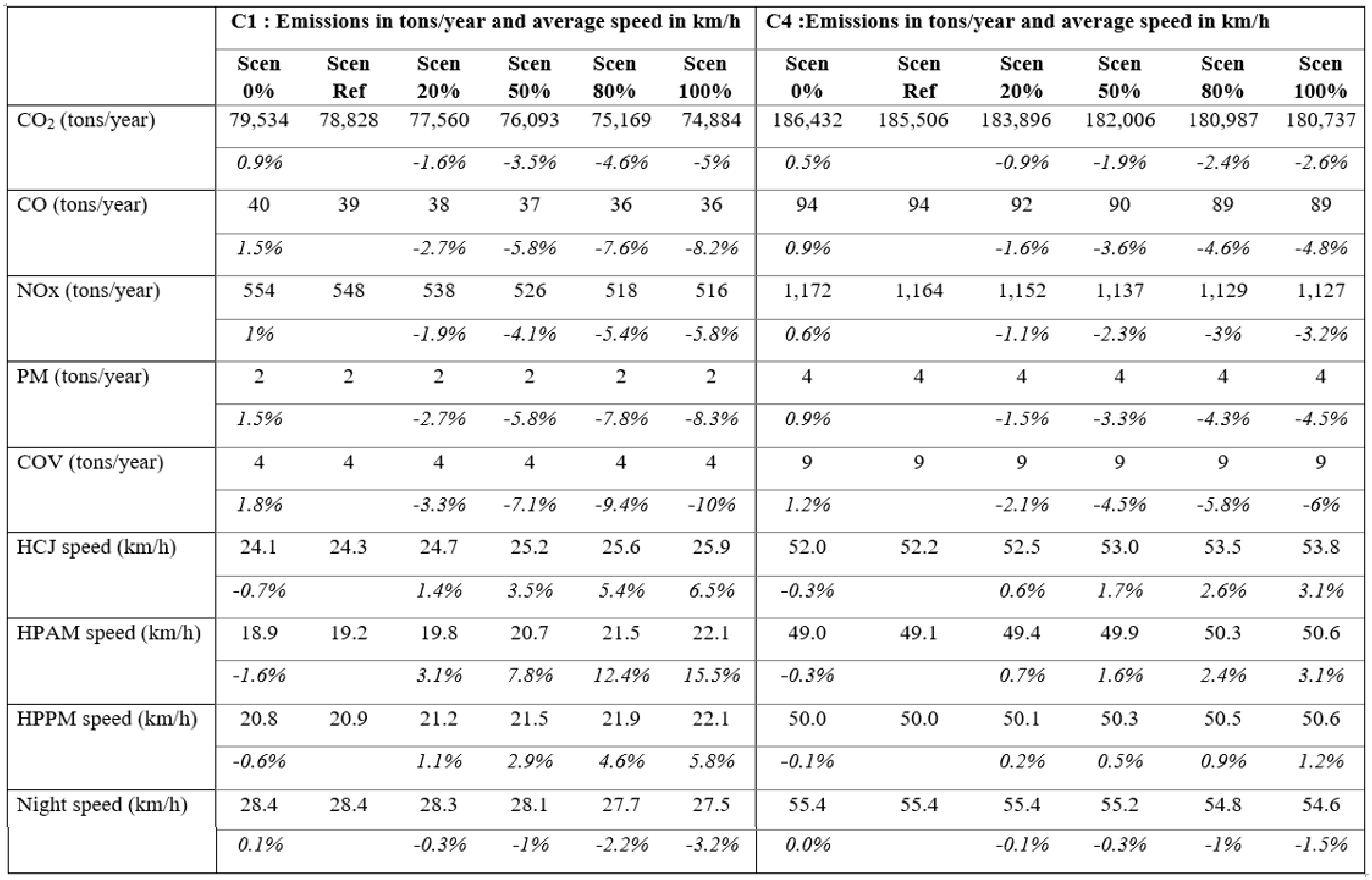
	Scen 0%	Scen Ref	Scen 20%	Scen 50%	Scen 80%	Scen 100%
CO_2 (tons/year)	385,246	382,778	378,468	373,360	370,384	369,584
	0.6%		*-1.1%*	*-2.5%*	*-3.2%*	*-3.4%*
CO (tons/year)	197	195	191	186	183	183
	1.2%		*-2%*	*-4.4%*	*-5.8%*	*-6.1%*
NOx (tons/year)	2,481	2,462	2,428	2,388	2,364	2,358
	0.8%)		*-1.4%*	*-3%)*	*-4. %*	*-4.2%*
PM (tons/year)	9	8	8	8	8	8
	1.1%		*-2%*	*-4.3%*	*-5.6%*	*-5.9%*
COV (tons/year)	20	20	19	19	18	18
	1.4%		*-2.6%*	*-5.6%*	*-7.3%*	*-7.6%*
HCJ Speed (km/h)	41.7	42	42.5	43.2	43.9	44.3
	-0.6%		*1.2%*	*3%*	*4.5%*	*5.5%*
HPAM Speed (km/h)	35.5	35.9	36.6	37.6	38.6	39.3
	-1%		*1.9%*	*4.8%*	*7.6%*	*9.6%*
HPPM Speed (km/h)	37.7	37.9	38.2	38.6	39	39.3
	-0.4%		*0.8%*	*1.9%*	*3%*	*3.8%*
Night Speed (km/h)	46.8	46.8	46.7	46.5	46.1	45.7
	0.0%		*-0.1%*	*-0.6%*	*-1.5%*	*-2.4%*

CO_2 emissions decrease by 1.1%, then by 2.5% and 3.4% respectively when the percentage of goods flows reported in OHD increases to 20%, then 50% and 100%. On the other hand, if the flows now carried out at night (8.9% of the total flow) were carried over to daylight hours (Scen 0%), emissions would increase by 0.6% for CO_2, 0.8% for NOx and 1.1% for PM. These results show that there is no threshold effect in relation to the gains in pollutant emissions that would be achieved by increasing the percentage of OHDs. As this percentage increases, so do the environmental gains, but less than proportionally. These gains are partly explained by the relative improvement in traffic conditions as the percentage of OHD increases.

Freight traffic emissions: densest area vs. least dense area

In C1, traffic conditions are the least favorable, given the high population and employment density (see **Table 2**). Any increase in the percentage of OHD leads to a relatively larger decrease

Table 3. CO₂ and pollutant emissions in C1 and C4



	C1 : Emissions in tons/year and average speed in km/h						C4 :Emissions in tons/year and average speed in km/h					
	Scen 0%	**Scen Ref**	**Scen 20%**	**Scen 50%**	**Scen 80%**	**Scen 100%**	**Scen 0%**	**Scen Ref**	**Scen 20%**	**Scen 50%**	**Scen 80%**	**Scen 100%**
CO_2 (tons/year)	79,534	78,828	77,560	76,093	75,169	74,884	186,432	185,506	183,896	182,006	180,987	180,737
	0.9%		*-1.6%*	*-3.5%*	*-4.6%*	*-5%*	*0.5%*		*-0.9%*	*-1.9%*	*-2.4%*	*-2.6%*
CO (tons/year)	40	39	38	37	36	36	94	94	92	90	89	89
	1.5%		*-2.7%*	*-5.8%*	*-7.6%*	*-8.2%*	*0.9%*		*-1.6%*	*-3.6%*	*-4.6%*	*-4.8%*
NOx (tons/year)	554	548	538	526	518	516	1,172	1,164	1,152	1,137	1,129	1,127
	1%		*-1.9%*	*-4.1%*	*-5.4%*	*-5.8%*	*0.6%*		*-1.1%*	*-2.3%*	*-3%*	*-3.2%*
PM (tons/year)	2	2	2	2	2	2	4	4	4	4	4	4
	1.5%		*-2.7%*	*-5.8%*	*-7.8%*	*-8.3%*	*0.9%*		*-1.5%*	*-3.3%*	*-4.3%*	*-4.5%*
COV (tons/year)	4	4	4	4	4	4	9	9	9	9	9	9
	1.8%		*-3.3%*	*-7.1%*	*-9.4%*	*-10%*	*1.2%*		*-2.1%*	*-4.5%*	*-5.8%*	*-6%*
HCJ speed (km/h)	24.1	24.3	24.7	25.2	25.6	25.9	52.0	52.2	52.5	53.0	53.5	53.8
	-0.7%		*1.4%*	*3.5%*	*5.4%*	*6.5%*	*-0.3%*		*0.6%*	*1.7%*	*2.6%*	*3.1%*
HPAM speed (km/h)	18.9	19.2	19.8	20.7	21.5	22.1	49.0	49.1	49.4	49.9	50.3	50.6
	-1.6%		*3.1%*	*7.8%*	*12.4%*	*15.5%*	*-0.3%*		*0.7%*	*1.6%*	*2.4%*	*3.1%*
HPPM speed (km/h)	20.8	20.9	21.2	21.5	21.9	22.1	50.0	50.0	50.1	50.3	50.5	50.6
	-0.6%		*1.1%*	*2.9%*	*4.6%*	*5.8%*	*-0.1%*		*0.2%*	*0.5%*	*0.9%*	*1.2%*
Night speed (km/h)	28.4	28.4	28.3	28.1	27.7	27.5	55.4	55.4	55.4	55.2	54.8	54.6
	0.1%		*-0.3%*	*-1%*	*-2.2%*	*-3.2%*	*0.0%*		*-0.1%*	*-0.3%*	*-1%*	*-1.5%*

in CO_2 and pollutant emissions than at the LUA scale. This is partly explained by the relatively larger variations in speed at this scale than at the LUA scale.

For all four periods, in C4, we note that the average speeds are relatively higher than those observed for the LUA, and even higher than for the C1. The results show a low sensitivity of the quantities of CO_2 and pollutants emitted into this ring as the percentage of OHDs increases. As this area is peripheral, these results were partly predictable since traffic conditions are good.

Environmental social cost

The maximum gain allowed by OHD in the study area is €2.59 million per year, a decrease of 3.9%. The scenario *0% OHD* leads to an increase in the environmental social cost of 0.7%.

Table 4. Environmental social cost of CO_2 and pollutant emissions (€ million /year)

	Cost by component					
	Scen 0%	**Scen Ref**	**Scen 20%**	**Scen 50%**	**Scen 80%**	**Scen 100%**
CO_2	34.67	34.45	34.06	33.60	33.33	33.26
NOx	32.39	32.14	31.69	31.16	30.86	30.77
$PM_{2.5}$	0.57	0.57	0.55	0.54	0.53	0.53
COV	0.03	0.03	0.03	0.03	0.03	0.03
	Total cost by area					
LUA	67.67	67.19	66.44	65.34	64.75	64.59
	0.7%		*-1.3%*	*-2.8%*	*-3.6%*	*-3.9%*
C1	14.6	14.5	14.3	14.0	13.8	13.7
	1%		*-1.8%*	*-3.8%*	*-5.1%*	*-5.5%*
C2	9.7	9.6	9.4	9.3	9.2	9.1
	0.8%		*-1.5%*	*-3.2%*	*-4.3%*	*-4.6%*
C3	11.2	11.1	11.0	10.8	10.7	10.7
	0.7%		*-1.3%*	*-2.8%*	*-3.7%*	*-4%*
C4	32.2	32.0	31.7	31.3	31.1	31.1
	0.6%		*-1%*	*-2.1%*	*-2.7%*	*-2.9%*

Table 4 shows that C4 is responsible for the highest share of the total cost (48%), but the most significant variations in cost according to the percentage of OHD are recorded in C1.

Distances and travel times evolution

We note a decrease in total travel time at the LUA scale of 11.3% for the 100% OHD scenario, representing a maximum absolute gain of 2.5 million hours per year (see **Figure 2 a)**. The time saved is undoubtedly an economic gain for carriers, since it can represent fewer working hours or be used to increase the number of points affected in each vehicle tour. The value of these hours of work gained is another argument in favor of OHDs.

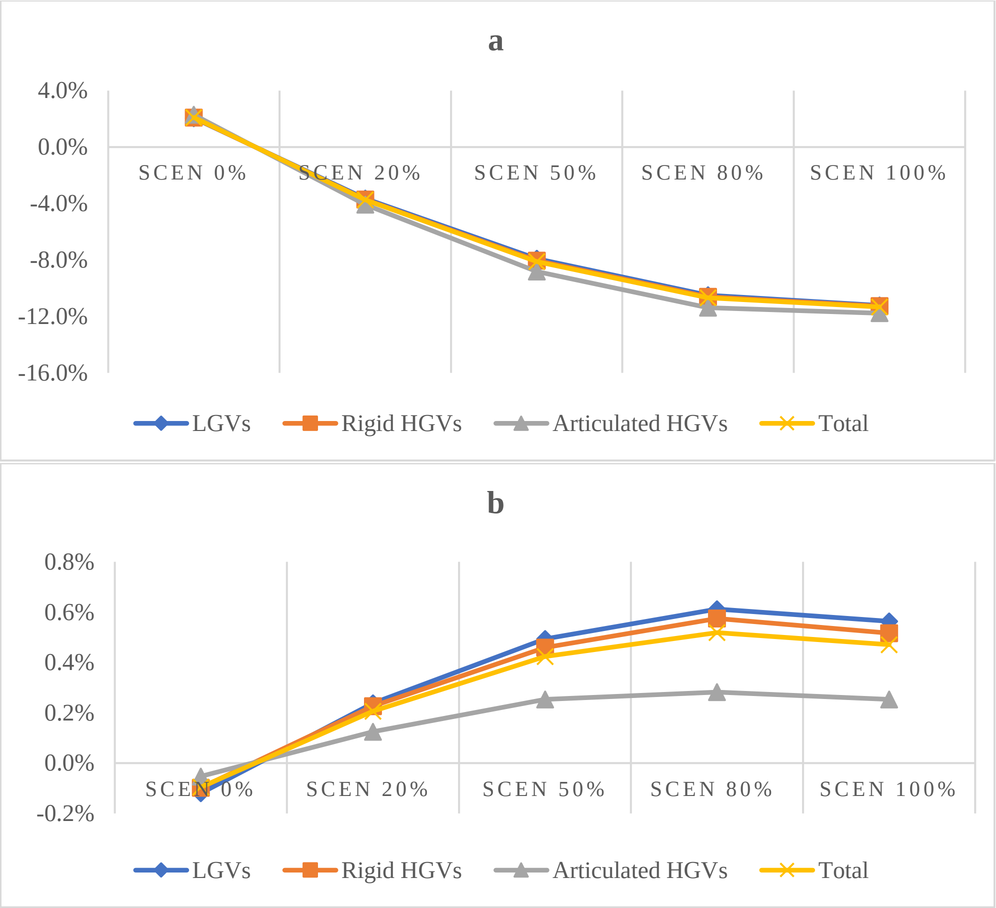


Figure 2. Variation of travel time (a) and distance traveled (b) in Vehicle kilometers (VKMs)

We observe a growth in distances travelled as the percentage of OHDs increases. However, this growth remains very low (less than 1%) and can be considered as insignificant (see **Figure 2 b**). OHDs do not therefore lead to a significant increase in the distances covered at the LUA level.

DISCUSSION

The results we are achieving show us that OHDs have a positive environmental impact in the case of LUA, although this is much lower than those obtained in small-scale experiments. Indeed, with a maximum reduction of 3.4% in CO_2 emissions, this is a far cry from the gains achieved of 13%, 64% and 48% per km travelled for Bogotá, NYC and Sao Paulo respectively (Holguín-Veras et al., 2016). These differences could probably be explained by some differences between the areas. In Holguín-Veras et al. (2016), the areas considered are NYC, São Paulo and Bogotá, respectively the third, fourth and sixth most congested cities in the world. This implies significant differences between peak and off-peak traffic conditions. This is not the case for LUA as shown in the data in **Table 2**. In addition, the hypercentre of the LUA is probably different from the american-style city with its wide avenues. Indeed, there is a strong presence of 30 km/h zones in the city of Lyon. This tends to limit the speed differences that can be observed between day and night, as shown in the data in **Table 3**. The variation in total travel time gives an idea of the level of improvement in traffic conditions that can be achieved with OHDs. While 10% of OHD in NYC reduces total travel time by 4% over a day (Holguín-Veras et al., 2012), only 3.7% of this time is reduced with 20% OHD on the LUA (see

Figure 2 a). Our results lead us to believe even more strongly that the magnitude of the environmental impact depends strongly on the characteristics of the city (e.g. traffic conditions, city size, number of inhabitants, density, etc.) in which they are implemented.

We can note some limitations to this paper. The traffic condition simulation tool, VISUM, used as a macro-simulation tool, may not be adapted to reproduce traffic conditions accurately enough. This can lead to accuracy losses when simulating traffic conditions in small areas. This type of tool, more suitable for simulating regional traffic conditions, may not fully consider the effects of traffic congestion (Ukkusuri et al., 2016). On the other hand, while simulation models at the meso and micro scales make it possible to better account for these effects, the calculation time makes them ineffective when trying to perform simulations at the scale of a city (Ukkusuri et al., 2016). The deliberate choice not to calculate the evolution of emissions due to PCs following the adoption of OHDs may be a limit to our results, since we do not know in absolute terms how the total environmental social cost of transport (passengers and goods) in the LUA evolves with OHDs. However, we believe that these limitations do not fundamentally affect our results. The environmental impacts of OHDs will be low in LUA but may be more effective if combined with other sustainable solutions of UGM like electric vehicles.

CONCLUSION

This paper assesses the potential impacts of large-scale implementation of OHDs, focusing on CO_2 and pollutant emissions from UGM in Lyon urban area. The methodological framework developed is composed by four steps: transport demand estimation, traffic simulation, emissions calculation and emissions environmental social cost calculation.

The results show that the environmental impact of OHDs is positive and increases with the percentage of OHD. When this percentage varies from 20 to 100%, the reduction in emissions goes from 1.1 to 3.4% for CO_2, 2 to 6.1% for CO, 1.4 to 4.2% for NOx, 2 to 5.9% for PM and 2.6 to 7.6% for VOC. This corresponds to a maximum reduction in the annual environmental social cost generated by the UGM of €2.59 million. Analysis of the results at the ring scale shows that OHDs have a greater relative impact in the densest areas. Thus, for a given percentage of OHD, the reduction in pollutant emissions is greater in the first ring than in the other three rings. It should be noted, however, that the environmental impacts of the OHDs recorded in this case study are low. They are much lower than what the literature attributes as the potential for OHDs to reduce the environmental impacts of UGM.

In addition, the analysis reveals that the adoption of OHDs makes it possible to save travel time. Indeed, we could save 2.5 million hours of travel time per year with 100% OHD. This represents a decrease of about 11% in travel time compared to the current situation. These time savings augur a productivity gain for carriers and the entire UGM. They could represent less working time or be used to extend the size of rounds if the vehicle load factor allows it. This opens study prospects through the simulation of the reorganization of delivery rounds and the calculation of productivity gains.

REFERENCES

Bertazzo, T., Hino, C., Lobão, T., Tacla, D., Yoshizaki, H., 2016. Business Case for Night Deliveries in the City of São Paulo during the 2014 World Cup, in: Taniguchi E., T.R.G. (Ed.), Transportation Research Procedia. Elsevier B.V., pp. 533–543. https://doi.org/10.1016/j.trpro.2016.02.009

Coulombel, N., Dablanc, L., Gardrat, M., Koning, M., 2018. The environmental social cost of urban road freight: Evidence from the Paris region. Transp. Res. Part Transp. Environ. 63, 514–532. https://doi.org/10.1016/j.trd.2018.06.002

Delaître, L., 2010. Barriers and Opportunities for Night Time Deliveries in Urban Context: A French Case Study. Presented at the World Conference on Transport Research, Lisbon, Portugal.

Holguín-Veras, J., Encarnación, T., González-Calderón, C.A., Winebrake, J., Wang, C., Kyle, S., Herazo-Padilla, N., Kalahasthi, L., Adarme, W., Cantillo, V., Yoshizaki, H., Garrido, R., 2016. Direct impacts of off-hour deliveries on urban freight emissions. Transp. Res. Part Transp. Environ. https://doi.org/10.1016/j.trd.2016.10.013

Holguín-Veras, J., Marquis, R., Brom, M., 2012. Economic Impacts of Staffed and Unassisted off-Hour Deliveries in New York City. Procedia - Soc. Behav. Sci., Seventh International Conference on City Logistics which was held on June 7- 9,2011, Mallorca, Spain 39, 34–46. https://doi.org/10.1016/j.sbspro.2012.03.089

Niches, 2006. Low Noise Solutions for Night Deliveries. Available at : https://www.polisnetwork.eu/uploads/Modules/PublicDocuments/os_aw_appl_dublin.pdf .

Nicolas, J.-P., Bonnel, P., Delgado, J.C., Godinot, C., Homocianu, G.M., Routhier, J.-L., Toilier, F., Zuccarello, P., 2009. SImuler les MoBilités Pour une Agglomération Durable. Rapport final du projet Simbad (No. halshs-01697687), Working Papers. HAL.

Ntziachristos, L., Gkatzoflias, D., Kouridis, C., Samaras, Z., 2009. COPERT: A European Road Transport Emission Inventory Model, in: Athanasiadis, I.N., Rizzoli, A.E., Mitkas, P.A., Gómez, J.M. (Eds.), Information Technologies in Environmental Engineering. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 491–504. https://doi.org/10.1007/978-3-540-88351-7_37

Ricardo-AEA, 2014. Update of Handbook on external cost of transport. Final report.

Routhier, J.-L., Toilier, F., 2007. FRETURB V3, A Policy Oriented Software of Modelling Urban Goods Movement. Presented at the 11th WCTR.

STRAIGHTSOL, 2014. STRAIGHTSOL Deliverable D6.3 (Analysis to the transferability opportunity to other urban-interurban contexts). Available at : http://www.straightsol.eu/deliverables.htm.

Ukkusuri, S.V., Ozbay, K., Yushimito, W.F., Iyer, S., Morgul, E.F., Holguín-Veras, J., 2016. Assessing the impact of urban off-hour delivery program using city scale simulation models. EURO J. Transp. Logist. 5, 205–230. https://doi.org/10.1007/s13676-015-0079-3