A MULTIMODAL TRANSPORT MODEL TO EVALUATE TRANSPORT POLICIES IN THE NORTH OF FRANCE

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A multimodal transport model to evaluate transport policies in the North of France

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***Abstract*—We develop a passenger transport model for the North of France and use it to discuss the impacts of some policies focusing on the limitations of emissions and congestion. The model is calibrated for the North of France, and includes both urban and intercity trips. Four transport modes are considered: walking, biking, public transport and private cars. The model is calibrated to match the mode shares and the dynamic of congestion along a full day. The simulations are conducted within the `MATSim` framework. We evaluate the impacts, on traffic flows and emissions, of two pricing reforms: free public transport and road pricing in city center of Lille (the main metropolitan area in the study region).**

***Index Terms*—Multimodal transport, Emissions and congestion, Transport simulation (MATSIM).**

I. INTRODUCTION

Urban and regional transport systems are important topics in pubic policies. Reducing the levels of congestion and polluting gas emissions are the main objectives underlying most reforms debated in recent years. The pandemic situation made these goals more urgent and widely shared, in particular those related to sustainable transport [1].

Policy analysis can be addressed through several perspectives. The usage of transport simulation tools has grown during the last decade, since they became more stable and accessible. Available datasets on travel patterns transport networks, such as `OpenStreetMap`, played an important role to facilitate the construction of realistic case studies. Also, more efficient algorithms are being used on faster computers and large scale simulations can now be conducted at reasonable costs.

The several steps underlying the development of transport models can be found in [2]. While difficulties related to the availability of the data no longer represent a main obstacle, the workflow in the modeling approach remains rather complex, in particular when dynamic traffic equilibrium is considered [3]. The calibration stage requires an iterative adjustment of the model parameters and remains a time consuming step. Other technical difficulties are related to the management and organization of large datasets, and the analysis of complex simulations outputs. These difficulties may partly explain why the number of cities and regions where an agent-based transport model has been set up remains limited, despite the relevance of these tools.

Agents' travel behavior is strongly related to their locations and their activities. A comprehensive transport model should, to some extent, take into account the nature of these activities, their duration and how they are chained during a typical day [4]. The `MATSim` framework used in our model is an activity-based transport simulator where each agent's utility is derived from the duration of the daily activities and users travel times to connect these activities [5].

This paper reports the main steps we undertook to construct a multimodal transport model for the North of France and identifies transport pricing policies that can reduce congestion and polluting gas emissions. We have tried to keep all the process as transparent as possible and adopted a modular approach allowing us to add components progressively to the model. We hope that this methodology facilitates the deployment of transport simulation models for other regions and cities. Most the data we have used is publicly available. This is the case for the road network and the income distribution of the population. For trip statistics, we use census data collected by the local regional authorities. The road network was manually complemented by the regional rail network, and data for public transport services `GTFS` files were used.[1]

For instance, four transport modes are taken into account: walking, biking, private cars and public transport (buses, regional trains, tramways, and the metro). As we notice in the conclusion, the model can be extended in several directions, other modes like car sharing and autonomous vehicles can be included without major difficulties. Multimodal trips are possible as users can combine two or more modes for a single trip.

This model is one of the first transport models to be developed in France at the regional scale. Earlier applications remain limited to the Paris and Lyon regions [6]–[9]. The study region covers the North of France with a population of four millions inhabitants distributed over 1 546 administrative jurisdictions. As we report in Section II, intercity trips are quite frequent and rush-hour congestion is severe in major motorways, especially, in the neighbourhood of the main agglomerations.

The paper is organized as follows. Section II provides a description of the data we have used to construct transport demand, the existing infrastructure and the public transport services. The calibration of the model is discussed in Section III. In Section IV we focus on some transport policies. We conclude in Section V.

[1]Most agglomerations in the study region provide such files. The model will be updated when new data will be made available.

II. The study region and input data

The objective of this research is to develop a multimodal transport model for the North of France. The study region covers the departments "Le nord" and the "Pas-de-Calais" as illustrated on Fig. 1. The total population in this region is about four millions inhabitants. There is a significant heterogeneity between the trips with respect to the purpose, the mode and the length. For example, within all the population there are about 1.2 millions persons having a daily trip longer than 10 km. For a simulation where only the regional scope matters, it may be appropriate to reduce the population size by taking into account only this group. Lille is the largest metropolitan area, with more than 1.1 millions inhabitant, and other major cities include Valenciennes, Dunkerque (Dunkirk), Calais, Boulogne-sur-Mer and Arras. The historical mining activities explain part of trip patterns observed between the mining area (the shaded region in Fig. 1) and other cities, Lille, in particular. Motorways around this city are severely congested during the peak hours. Also, the "A1" motorway is a main connection for freight transport between northern Europe, Paris region and other southern cities in the south of France and Spain. The region itself is a main place for logistics activities, including warehousing, since it connects several ports (Dunkerque, Calais and Boulogne-sur-Mer) and multimodal platforms (Dourge, located south in the south of the agglomeration of Lille).

Fig. 1: The region covered by the model (North of France). The two departments, "Le nord" and "le Pas-de-Calais" are represented as well as the historical mining region.

The model has several variations. Basically it is a regional model, but the focus on a particular (sub-)region or a given city is straightforward. We particularly consider the cases of the agglomerations of Dunkerque and Lille. Other variations are considered with respect to users heterogeneity with respect to income, available transport modes and how mode combinations are possible.

A. Census data on daily trips

The model includes four modes "walk", "bike", "car" and "public transport", and allows for their combinations (to some extent). It covers both urban and intercity trips. Survey data from the Regional Household survey of 2016 is used to build daily trips. Mode shares are shown in Fig. 2. The usage of the private car is the dominant mode, and most short trips, less than one kilometer, are made by walk. Public transport modes are used for urban (bus and metro) and intercity (train) trips. Other modes, like tramways and intercity buses, have a very small share and are not reported here. The data we use covers all trips departing and arriving insider the study region, but also inflows and outflows with other regions in France. Our simulation model include all these trips. But it does not include traffic cross-border traffic. As we explain below, it is complemented, at the calibration stage, by the census data, to include cross-border traffic and freight transport.

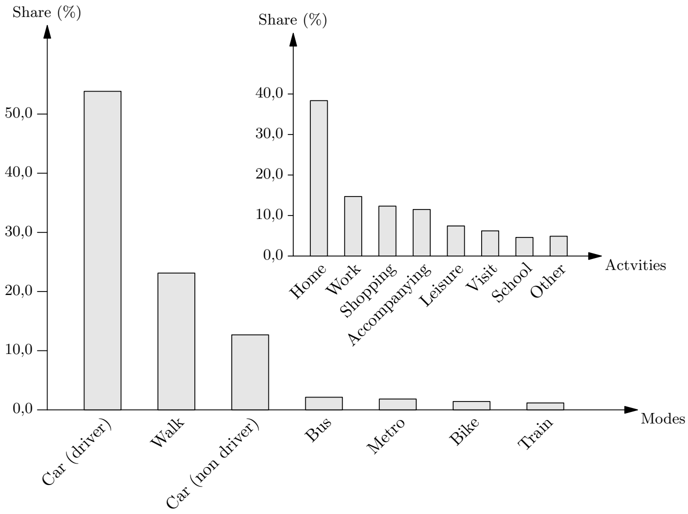

Fig. 2: The main figure shows mode shares for daily trips (only main modes are reported). Activities and their relative importance, whether they appear at the origin or at the destination of a trip, are reported in the upper right corner.

For each trip, the survey data reports several activities as the trip purpose, at the origin or at the destination. The smaller panel in Fig. 2 reports the most important trip purposes. The most frequent ones are "home", "work", "shopping" and "accompaniment" (family or friends). These values are reported for the whole population and should, of course, significantly differ when we focus on specific group with respect to age or jobs qualification.

Departure and arrival times of the trips are given in the main panel in Fig. 3. The dynamic is standard with two main peaks occurring in the morning and the evening, respectively. A relative increase in traffic flow is also observed in the midday. The length of the delay of arrivals increases with travel times. This delay is indeed clear during peak hours when congestion is high.

B. Cross-border and freight transport

To obtain realistic traffic flows we need to add cross-border trips and freight transport. Unfortunately, there are no com-

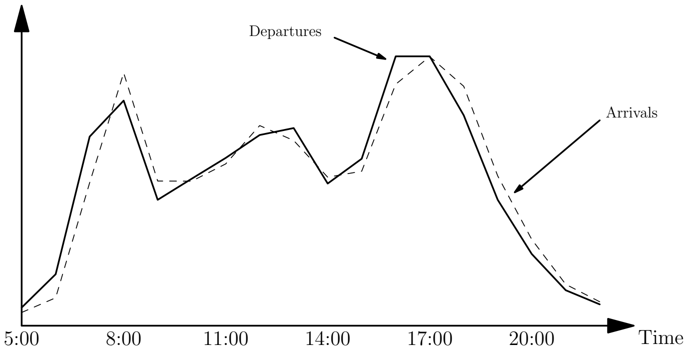

Fig. 3: The dynamic of traffic flows during a representative day.

prehensive datasets available to use for this purpose. Cross-border trips are important since the study region is adjacent to Belgium borders and cross-border commuting is central to several regional policies focusing on the development of European metropolitan Areas.

To overcome the lack available information on cross-border traffic flows, we use census data for home-to-work trips, which is available at the scale of the "commune". The database reports only flows departing from France to Belgium and not trips in the opposite direction. We assume a symmetric distribution of the trips and generate a random flow from Belgium to the study region in France. At the destination, these trips are directed towards most important agglomerations, i.e. activity zones.

Freight transport is not yet fully implemented in our model. The main reason is again the lack of an available database for these trips. Freight transport remains an important part of traffic flows since several logistic activities are taking place in the North of France. This region is crossed by the A1 motorway that connects the countries in the North (Netherlands, Belgium) to Paris and southern regions in Europe. To include representative traffic flows we produce freight transport, along the motorways crossing the study region, that matches counting data for trucks running on the corresponding links. We check that the calibrated model produces a congestion dynamic that corresponds to observations.

C. Incomes and the synthetic population

Incomes distribution are available at the level of the communes. For communes with a small population, only the median income is provided. For very small communes, with some dozens inhabitants, no information is given in order to keep the information anonymous. We assign incomes to each person by using the following procedure. For each person, we check if the distribution (by decile) is provided. In that case we draw a random income from the cumulative distribution corresponding to the deciles. If only the medium income is given, then we shift the last decile distribution to match the medium income and draw a random income accordingly. If no information is given for the commune, we draw a random income from the last available distribution. Given the spatial

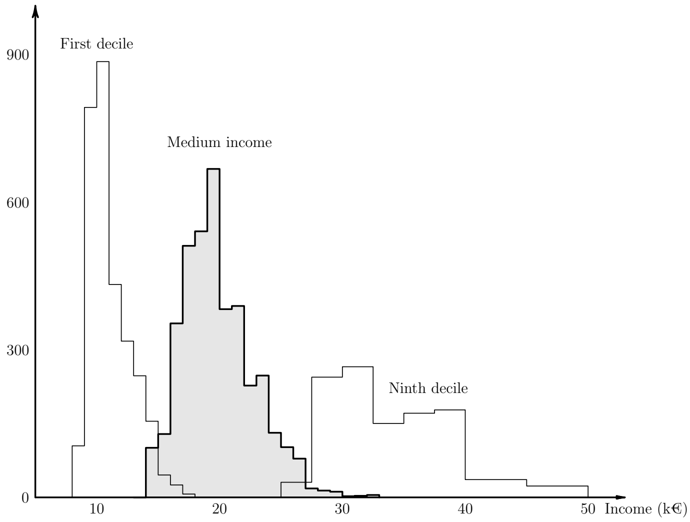

Fig. 4: Revenue distribution for the study population (selected deciles).

scope of our model, the loss in information should not be large since small differences exist between the commune.

Income distribution is described in Figure 4 which provides three curves, respectively, corresponding the first, fifth and ninth deciles. The lowest 10% incomes are the most concentrated between 8 000 and 15 000. The highest 10% incomes are much more dispersed and range from 25 000 to more than 50 000. The medium incomes are about 20 000. Overall, the income in the North of France is smaller than the average income in France. The population is subdivided into three groups that we refer to as "low", "medium" and "high" incomes groups, respectively. The threshold income between low and medium groups is 11 000 euros and the second threshold, between medium and high groups is 23 000 euros. There are 499 060, 1 568 380 and 871 510 users, respectively, in the low, medium and high income groups.

To run large-scale simulations, it is difficult to include the whole population. Each iteration needs a long time, and the calibration, which requires a large number of iterations, becomes unpractical. It is a usual practice, including in `MATSim`, to work with a synthetic population, instead. The idea is to consider only a proportion of the population, uniformly drawn from the initial population, and scale down the network capacity, so that traffic congestion and public transport flows remain consistent. Several sampling levels, ranging from less than 1% to 50%, were used in our simulations. With a very small population the simulations can be run quickly but do not produce very representative outputs. At this level, the simulation were mainly designed for testing and checking the code. Large samples produce realistic traffic flows but require more time to run. The results reported here are produced with a 10% and 30% synthetic population.

D. Infrastructure and public transport services

For the road network, we have used the open database provided by IGN[2], which is derived from `OpenStreetMap` databases with some corrections and standard formatting. This database provides the attributes of each link (speed limit, capacity, number of lanes, etc.) and is globally satisfactory for the road network. The road network has has a large number of links that are grouped with respect to their importance (motorways, main links, secondary roads, etc.). The main limitation is the incomplete rail network which is composed of a dozen of service lines. We have then manually added the train lines, and corresponding stations, directly in the `MATSim` format.

Public transport includes several urban bus networks, the TER (and TERGV) network, metro and tramway in Lille. The public transport fleet consists of 14 748 vehicles spread over the conurbations of Lille (Fig 6), Dunkerque, Boulogne sur Mer, Calais, Valenciennes and Saint Omer, in addition to the region's rail network. The modelled network reflects the actual situation and is composed of 218 438 nodes and 485 072 links.

Public transport services include buses, operating at the urban and suburban areas, tramways, in Lille and Valenciennes, the two automated metro lines in Lille and the regional trains. Fast train lines also connect Lille to Dunkerque and Boulogne-sur-Mer. Most bus services are available in `GTFS` files provided by local operators. Some small local operators have not yet published the timetables of their services (Cambrai, Lens, Douai, Arras), but this does not have an important impact on simulated traffic given the relative size of the flows. The model will be updated when this data is made available.

III. Calibration

A topic issue in traffic modeling is the calibration of the model. The objective of the simulation is to produce realistic traffic flows over the study region and with respect to the set of transport modes considered (Fig. 5). We focus on mode shares and optimize modes specific constants so that after several iterations the model converges to observed mode shares. A plan is a sequence of activities, each one except the last, is followed by a trip. In the utility function, a constant is attached to each mode. An increase in the value of the constant increases the share of the corresponding mode and vice versa. The formulation adopted in this model has an additive utility in the form

$$U_{\text{plan}} = \sum_{a=0}^{N} U_a - \sum_{a=0}^{N-1} C_a(m), \tag{1}$$

where U_a denotes the utility from activity a and $C_a(m)$ the user cost related to transport occurring after the activity a when the user chooses transport mode m (there are no transport after the last activity). The utility related to an activity depends on its duration and the schedule delay cost if the user arrives early or late to the activity. Several formulations are possible to reflect the interactions between these variables. For this model we use the `CharyparNagel` formulation [5]. The user cost of a trip by mode m between activity a and activity $a+1$ is given by

$$C_a(m) = c_m + \beta_t\, t_{m,a} + \left(\beta_m + \beta_I\, \gamma_m\right) d_a + \chi_a, \tag{2}$$

where c_m is a mode specific constant (shift parameter), β_t is the opportunity cost of travel time, t_m is travel time to go from activity a to activity $a+1$. β_m is the monetary cost per unit distance of mode m. This parameter is usually zero for motorized modes and positive for non-motorized ones (bikes, walk, etc.). It reflects physical effort deployed. β_I is the marginal utility of income. γ_m is a mode specific monetary cost, d_a is the travel distance between activity a and activity $a+1$ and χ_a is a transfer cost between activity a and activity $a+1$, if any. This formulation of the user cost reflects the intuition that users dislike trips with long durations and long distances, in particular if they do not use motorized modes.

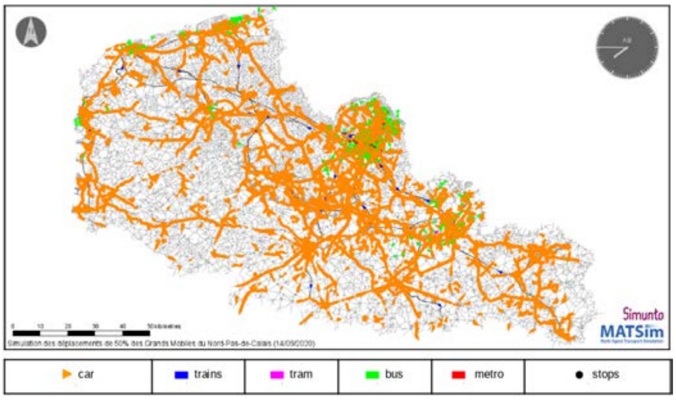

Fig. 5: The region covered by the model (North of France).

The calibration's objective is to adjust the parameters of the model so that it replicates observed traffic flows. Usually models focus on mode shares and travel duration. With several modes, the calibration may not be straightforward since several parameters must be adjusted smoothly for a function which costly to evaluate. We use a standard error function with respect to mode shares: for some specific mode constants we run a simulation until it reach the stationary situation, then compare the obtained mode shares with observed one (given in Fig. 2). New shift parameters are then computed with the objective to reduce the gap. We use the following rule for the update

$$c_q^{\text{new}} = c_q^{\text{old}} - \log\left(\frac{P_q^{\text{mod}}}{P_q^{\text{ref}}}\right). \tag{3}$$

A mode is more attractive when the shift parameters increases and vice versa. The idea here is to increase the value of the shift parameter when mode m is underused in the last iterations produced by the model. More sophisticated techniques to find the best values of the shift parameters can be used. We intend to improve this step in future research.

When the model produces a distribution of mode shares close to the observed distribution we check if traffic flow and

[2]https://geoservices.ign.fr/documentation/diffusion/index.html

travel times reflects realistic trends. In our case, the calibration process was satisfactory with respect to this test. Traffic flows for the study region is illustrated in Fig. 5. It displays traffic flows for cars and public transport modes, and shows an important congestion on the main road links. A focus on the Lille metropolitan area is given in Fig. 6, where public transport modes (buses, trams and metro) are easier to observe.

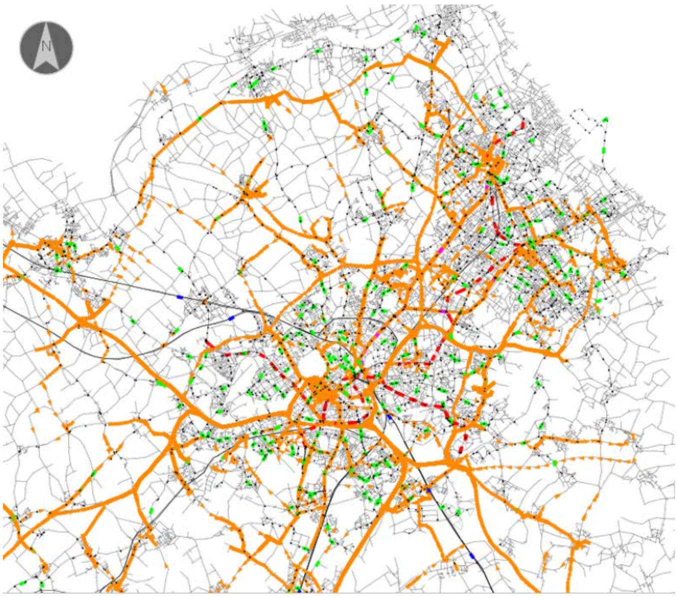

Fig. 6: The model scaled on the metropolitan region of Lille (the same legend as in Fig. 5).

IV. Transport policies

In this section, we consider some reforms of transport pricing that aim at reducing emissions and congestion. Road transport is a source of large external costs [10] and the objective of most transport policies is to reduce the usage of private cars. Two main scenarios are examined: (i) free public transport on all the study region, and (ii) road pricing in the agglomeration of Lille. In the first, public transport is made free on all the study region. This includes both urban modes (buses, tramways, metro) and intercity modes (regular trains and fast trains). Reducing fares of public transport aims at attracting more users in the mass transport and could favor low income households. It raises the issue of collecting revenues to operate the existing services, and those produced for the induced demand, but may reduce operating costs since there are no fare collection. In the absence of road pricing free public transports should reduce congestion external costs and emissions, insofar it reduces the usage of the private cars.

Road pricing is, for many economists, the most efficient tool to reduce congestion and emissions to their efficiency level. Users generally oppose the implementation of road pricing schemes because they see it as an additional tax [11]. Issues related to road pricing are the cost of collecting fares and controlling for the adherence of road users. These technical difficulties are now less important, thanks to the geolocation technologies and low cost of surveillance cameras. Several cities has now adopted road pricing (London, Oslo, Singapore, etc.) and several others are considering road pricing in their transport policies.

Modes	User groups			Total	(%)
	low	medium	high		
Regional model: Nord and Pas-de-Calais					
bike	24687	15637	9311	49635	3.29
car	111976	461970	259400	833346	55.19
pt	23021	51675	31938	106634	7.06
walk	106516	263706	150025	520247	34.46
Urban model: Lille					
bike	4328	13574	3306	21208	6.71
car	28442	118725	105533	252700	44.23
pt	10834	29568	25311	65713	11.50
walk	39418	109102	83245	231765	40.56

TABLE I: Base case: mode shares of the calibrated model.

For the two main scenarios, we focus on traffic flows (the level of congestion) and emissions. The reference values are those obtained in the calibration stage and given in Table I for the whole study region and for the metropolitan area of Lille. Travel modes are reported for each group. Biking share remains small by comparison to the other modes, but it is twice as important in Lille (urban transport). Similarly, walking and public transport are more used in Lille (and other urban areas). The private car, which is the source of important congestion and emissions, is dominant, in particular for intercity trips where it accounts for more than 50% of total flows. Walking is important, but public policies cannot be based on a shift to this mode because it only concerns very short trips.

A. Free public transport

The agglomeration of Dunkerque, with more than 200 000 inhabitants is the largest city in France offering free public transport services. Lille offers free public transport for those who are less than eighteen years old starting from January 2022. The issues of free public transport has been largely debated in the regional elections that took place in June 2021, several regions including the North of France and the metropolitan area of Paris. Attracting users of the private cars is one of the main objectives of free public transport. The precise magnitude of this impact will depend on the cross elasticities between the modes and these are generally low [12], [13]. Free public transport is sometimes criticized as mainly attracting walkers and bikers, and not really much of the users of the private cars. Unpriced public transport has other benefits. In particular, it improves the mobility of the low income group [14] and contributes to reduce frictions in the labour market [15].

To evaluate the impacts of free public transport, we consider the model where the population is composed of three groups as described in Fig. 4, and remove the monetary cost for users of public transport. This is made for the whole regional transport system, and it is straightforward to limit this measure to a specific agglomeration.

	User groups			
Modes	low	medium	high	Total
bike	-20.27	-18.32	0.00	-13.26
car	-18.19	-16.05	0.00	-11.99
pt	+62.99	+72.64	0.00	+50.31
walk	+10.20	+14.97	0.00	+10.16

TABLE II: Impact of the free public transport on mode shares.

	User groups			
Modes	low	medium	high	Total
bike	+13.34	+14.96	0.00	+12.52
car	-4.01	-3.89	0.00	-2.32
pt	+2.21	+3.04	0.00	+1.73
walk	+0.82	+1.55	0.00	+0.89

TABLE III: Impact of the cordon toll on mode shares.

The aggregate simulation outputs for free public transport are reported in Table II. Removing fares creates an important modal report on public transport. The number of trips with this mode increases by more than 50% at the aggregate level, and even more for the low and medium income groups. We have set a very small value of cross elasticity for the high income groups based on the assumption that users in this group are less likely to change their mode. They are less sensitive to monetary costs. The attractiveness of public transport leads to a decrease in the usage of the substitutes. Indeed, the private car usage decreases by about 11% while the number of bikers decreases by a slightly higher amount. Walking is more frequent since it is a direct complement for public transport.

B. Road pricing

The objective of road pricing is to make the users bear the full cost of their trips, including the social marginal cost they impose on other users [16]. First-best tolls are generally difficult to implement since they require the availability of quantity of information for each single trip (departure and arrival times, route choice, vehicle characteristics, etc.). [17] show that first-best toll is time-varying that increases during the peak hours when congestion level is high. In practice, more simpler pricing schemes are adopted. For example, Zone tolls, where users pay a charge for driving within a given zone (city center), is used in London. Alternatively, in Norway for example, cordon tolls are used, instead. In this case, users pay a charge when they cross a border between two zones, usually the city center and the periphery. Which pricing scheme is better will generally depend on the cities geometry and the trade-off between simple schemes and efficiency. The outcome can also depend on whether we focus on the short term impacts (fixed location of households and activities) or the long term impacts where households and firms are allowed to relocate to optimize the trade-off between accessibility and benefits of real estate services (housing of office space). [18] discuss several cases and show that cordon tolls remain simple and usually reach a good efficiency, in particular, in the long run when households can relocate.

We focus here on the metropolitan area of Lille, which is the largest agglomeration in our study area, and evaluate the impacts of a cordon pricing covering the city center and a small part of the motorways A1 and A25. This is important since during peak hours, these two motorways are severely congested. Also, agglomeration of Lille is somewhat sprawl with a CBD (Central Business District) in the city center, but several other SBDs (secondary business districts) as reported in [19]. So, congestion is not particularly important in the city center but in the periphery. This pattern is accentuated as a significant part of home-to-work trips connect the (historical) mining basing (cf. Fig.1) to the agglomeration of Lille.

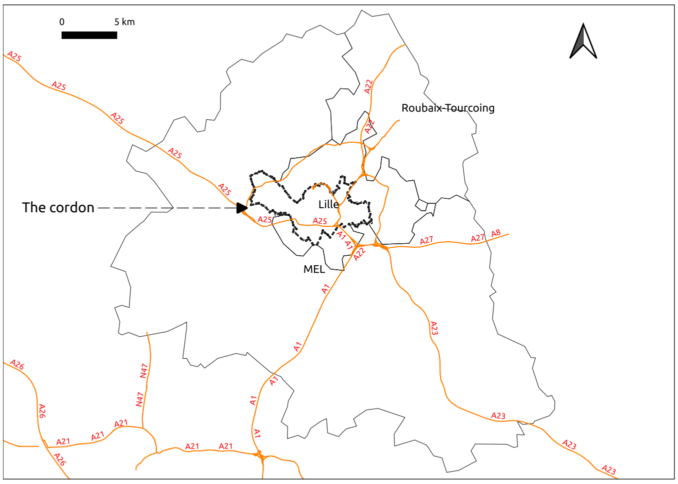

Fig. 7: The cordon toll area (Lille agglomeration).

The cordon toll area is given in Fig. 7. Tolls are imposed on private cars in each crossing of the cordon. For some trips, like those going through motorways A1 and A25, the toll is paid twice. Drivers can avoid the toll by using secondary roads or other highways. Drivers living (resp. working) inside the cordon area and working (resp. living) outside the cordon area pay the toll at least once. They may switch to public transport to avoid the toll, and low income groups are more likely to do so, than high income groups.

The main impacts of the cordon toll are given in Table III. The usage of private cars decreases by 2.32% and this concerns low and medium income groups. There no modal switch for the high income since, as we mentioned above, we have set a small cross-elasticity for this group. An important modal switch occur in favor of micro-mobility, i.e. biking. The latter is quite flexible for urban trips, where is is a potential substitute for the private car. The public transport mode is more attractive but with a limited magnitude. This can be explained by the fact that public transport services are not available for the trips crossing the cordon. In the full comparison of the two scenarios, one must take into account also the financial balance of each. Indeed, free public transport need financial resources, as users do not pay for the corresponding services, while road pricing, here cordon toll, generates additional revenues.

V. Conclusion

We have developed a multimodal transport model for the North of France, and used it to discuss some reforms that focus on the reduction of external costs (pollution, congestion) produced by transport activities. Since both urban and intercity trips are taken into account, this model can be used to study policies at the regional and/or urban scale.

The model has several interesting features. It includes several modes of transport (motorized and non-motorized) and is based on dynamic assignment structure [3]. Our approach is modular and transparent and should be relatively easy to replicate for other regions. It already includes most available data on travel patterns in the study region and can be updated as soon as new data is made available. For example, service schedules of public transport can be updated to new changes or new published schedules.

We have reported the main results for the first two scenarios that we have examined. Free public transport could attract a large number of users to mass transit. This will be followed by a significant reduction in the number of users of the private car. Overall, the congestion level decreases and a positive impact on the level of pollution is expected, too. Cordon pricing yields also positive impacts but with a limited magnitude. The decrease in the usage of the private car is relatively small and is comparable to the modal switch to public transport. There is, however, a significant increase in biking (+12.52%), which is important for the development of an urban sustainable transport. The limited impact of the cordon toll we have examined should not be generalized to all road pricing schemes. We may obtain distinct outcome with zone tolling (drivers pay a toll when they drive inside a given zone). Also, better impacts may be possible if the cordon tolls that are set on a narrower or larger area. The level of the toll may also be optimized to obtain higher impacts. Further investigations, that we plan to conduct in the near future, is necessary before we can definitely conclude with this respect to this issue. As we discussed above, financial balance of each scheme should be taken into account for a full comparison of the competing policies.

The model can be improved in several directions. The first one may be the usage of a sophisticated calibration techniques. The procedure we have uses, and based on Eq. (3), is very simple and does not always converge, in particular, when the number of control parameters is large (more than ten). The number of parameters increases, for example, when there several groups of agents. In that case, a manual adjustment was necessary to complement the automatic update of the model parameters. Appropriate procedures based on Broyden's algorithm for non-linear equations should yield better outcomes. Doing so, will allow us to implement finer calibration based on count data. Other extensions could consider a more comprehension account of multimodal trips. In the current version, the combination of several transport modes is not very flexible and limited to some predetermined possibilities. The other possible improvement is related to the utility function. For instance we use a basic formulation where all the component enter linearly. More complex formulation are more consistent with micro-economic description of the users' choice. In particular, travel time uncertainty turns out to be important an important determinant in the choice of the transport mode (and even the households' location choice). A recent literature has focused on this topic during the last decade and several estimations confirm that travel time reliability is as important as the value time.

Finally, we may notice that the model can be used to examine several other scenarios. More sophisticated scenarios can be examined. In particular, a complex time-varying tolls may produce a much better impact than flat cordon tolls [17]. The list of possible policies is quite long. Those which are of first importance for our research agenda are automated and shared vehicles, electric vehicles and the related energy and pollution impact, etc. Given the current pandemic context, an important theme is to study how to adapt public transport services to health emergency situations and how to recover pre-pandemic traffic flows in the public transport sector.

Acknowledgement

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References

[1] W. Marek, "Will the consequences of covid-19 trigger a redefining of the role of transport in the development of sustainable tourism?" *Sustainability*, vol. 13, no. 4, p. 1887, 2021.

[2] J. de Dios Ortúzar and L. G. Willumsen, *Modelling transport*. John wiley & sons, 2011.

[3] L. Brotcorne, D. De Wolf, M. Gendreau, and M. Labbé, "A dynamic user equilibrium model for traffic assignment in urban areas," in *Transportation and Network Analysis: Current Trends*. Springer, 2002, pp. 49–69.

[4] M. G. McNally and C. R. Rindt, "The activity-based approach," in *Handbook of Transport Modelling*. Emerald Group Publishing Limited, sep 2007, pp. 55–73. [Online]. Available: https://doi.org/10.1108%2F9780857245670-004

[5] K. W. Axhausen, A. Horni, and K. Nagel, *The Multi-Agent Transport Simulation MATSim*. Ubiquity Press, aug 2016. [Online]. Available: https://doi.org/10.5334%2Fbaw

[6] D. Nguyen-Luong, A. de Palma, K. Motamedi, H. Ouaras, and N. Picard, "Simaurif: Simulation of the interaction between land use and transportation in the region ile-de-france (paris region)," in *European Transport Conference 2008; Proceedings*, 2008.

[7] J. Delons, N. Coulombel, and F. Leurent, "PIRANDELLO an integrated transport and land-use model for the paris area," 2008.

[8] A. De Palma and F. Marchal, "Real cases applications of the fully dynamic metropolis tool-box: an advocacy for large-scale mesoscopic transportation systems," *Networks and spatial economics*, vol. 2, no. 4, pp. 347–369, 2002.

[9] C. Raux, T.-Y. Ma, R. Lemoy, and N. Ovtracht, "A luti agent-based model of Lyon area: welfare analysis of some scenarios," *Transp Res Arena (TRA)*, 2014.

[10] K. B. Abdallah, M. Belloumi, and D. De Wolf, "International comparisons of energy and environmental efficiency in the road transport sector," *Energy*, vol. 93, pp. 2087–2101, 2015.

[11] B. De Borger and A. Glazer, "Support and opposition to a pigovian tax: Road pricing with reference-dependent preferences," *Journal of Urban Economics*, vol. 99, pp. 31–47, 2017.

[12] P. Goodwin, J. Dargay, and M. Hanly, “Elasticities of road traffic and fuel consumption with respect to price and income: a review,” *Transport reviews*, vol. 24, no. 3, pp. 275–292, 2004.
[13] T. Litman, “Transit price elasticities and cross-elasticities,” *Journal of Public Transportation*, vol. 7, no. 2, p. 3, 2004.
[14] L. A. Guzman, D. Oviedo, and R. Cardona, “Accessibility changes: Analysis of the integrated public transport system of bogotá,” *Sustainability*, vol. 10, no. 11, p. 3958, 2018.
[15] N. Pilegaard and M. Fosgerau, “Cost benefit analysis of a transport improvement in the case of search unemployment,” *Journal of Transport Economics and Policy (JTEP)*, vol. 42, no. 1, pp. 23–42, 2008.
[16] K. A. Small and E. T. Verhoef, *The economics of urban transportation*. Routledge, 2007.
[17] A. de Palma, M. Kilani, and R. Lindsey, “Congestion pricing on road network: A study using the dynamic equilibrium simulator metropolis,” *Transportation Research A*, vol. 39, no. 7-9, pp. 588–611, 2005.
[18] M. De Lara, A. De Palma, M. Kilani, and S. Piperno, “Congestion pricing and long term urban form: Application to paris region,” *Regional Science and Urban Economics*, vol. 43, no. 2, pp. 282–295, 2013.
[19] A. Aboubacar, H. Hammadou, and M. Kilani, “Distribution des emplois et identification des sous-centres d’affaires dans l’agglomération lilloise,” *Revue dEconomie Regionale Urbaine*, no. 5, pp. 913–936, 2019.