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Decoupling accessibility and automobile mobility in urban areas

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Abstract

The aim of this article is to see to what extent it is possible to tend to cities where accessibility will be decoupled from the speed of car travel.

In this context, as a first step, we simulate different policies of speed regulation and investigate their effects on modal split, distances travelled, and people satisfaction using a multi-agent simulation tool and taking Zurich (Switzerland) as a test case.

As it appears that the effects of regulation of speed alone is insufficient to reach both a more sustainable mobility and to preserve individual satisfaction, we couple it, in a second step, with an optimal relocation of urban amenities using a specifically developed methodology. The results show that this double action (on speed and amenities location) may be able to provide a slower but accessible town which will, in addition, preserve the individual satisfaction: the sustainable mobility city.

Keywords: Accessibility, sustainable mobility, multi-agent system, optimal localisation method

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Résumé

L'objectif de cet article est de voir dans quelle mesure il est possible de tendre vers des territoires urbains où l'accessibilité serait découplée de la vitesse automobile. Dans cette perspective, nous simulons dans un premier temps pour Zurich (Suisse) différentes politiques de régulation des vitesses automobiles et étudions à l'aide d'un système multi-agents leurs effets sur le partage modal, les distances parcourues et la satisfaction des individus. La seule action sur les vitesses ne permettant pas de tendre vers une mobilité plus durable tout en assurant la satisfaction individuelle, nous couplons dans un deuxième temps l'action sur les vitesses automobiles avec une action de relocalisation optimale des aménités urbaines grâce à une méthode ad hoc. Les résultats obtenus montrent que cette double action (sur les vitesses et les localisations) est en mesure de permettre de tendre à terme vers une ville plus lente mais accessible assurant en outre la satisfaction des individus: la ville de la mobilité durable.

Mots-clé: Accessibilité ; mobilité durable ; système multi-agents ; méthode de localisation optimale

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1. Why we need to change the nature of accessibility in urban areas

Accessibility can be defined as the capacity to reach locations or resources (jobs, services, social contacts, etc.) within a given travel time. This capacity depends on the transportation mode used, its characteristic speed and its capacity but also on the location of resources (amenities). Unfortunately, in urban areas for the last forty years, planners had the tendency to “forget” that location of amenities is an important component of accessibility (notably in France), leaving to the transportation system the responsibility to provide people with good accessibility to those amenities. Increasing transportation speed (above all car speed) was supposed to provide a good accessibility to people. In other words the idea has been: however jobs, shops or leisure opportunities are located in urban areas, providing the necessary infrastructure for cars - and therefore allow fast car travel - means providing good accessibility to individuals for their daily needs. So, maintaining or improving travel speed appeared more important than thinking about locations. Transportation overrides geography.

At the individual scale, fast car travel allows people to choose their home location in large areas, because it provides proximity in time between those and the locations of their activities (within the limit of the Zahavy conjecture, that is to say a daily transportation time budget of more or less 1.5 hour, (Zahavy, Talvitie, 1980). Consequently, the availability and the use of fast car travel appear to be a driving force of the urban sprawl phenomena and its consequence on mobility practices (Wiel, 2002).

Moreover, if we analyse precisely the type of accessibility provided by car, it appears from a planning perspective, that road networks do not play a fair game. Indeed, as current road networks are highly hierarchized by speed, the farther you go, the more you use roads which allow you to drive faster – assuming you are looking for a shortest path in time - and so the more efficient is your travel.

Comparing the performances provided by several road networks for different range of travels in terms of efficiency, which is an average speed defined as the Euclidean distance between origin and destination of a trip divided by the duration of the trip (Gutierez et al., 1998), shows evidence of this phenomenon. If we plot the index of efficiency against the distance travelled (Fig. 1), we can notice that, on average, the level of performance increases non-linearly with the distance travelled.

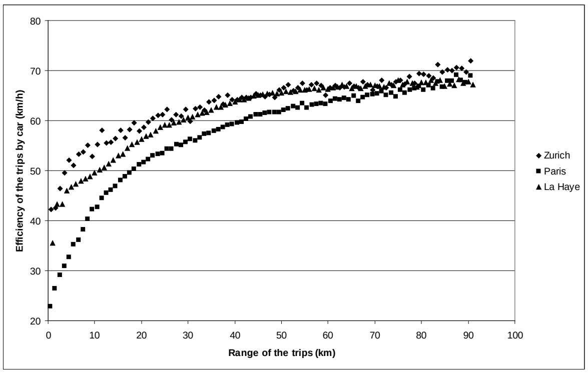

Fig. 1. Variations of the automobile efficiency with the range of the travels.

The consequence of this “speed metric” is that it ensures travellers the possibility to drive farther without necessarily increasing their transportation time in the same proportion. In other words, according to the ratio between the number of opportunities that can be reached and the duration of the travel, the speed metric encourages people to stay on the network with their car, as every additional second spent on the network provides a higher gain in terms of accessibility than the previous one (Foltête et al., 2011).

Moreover, this speed metric merely concerns cars, as public transportation modes (bus, tramway) are restrained by the frequent stops they have to make along their route. As a consequence, the structure of road networks intrinsically favours the use of car, especially for the longest distances.

Therefore, the metric of current road networks goes against the objectives of urban planning, as it allows and even encourages car use, separation between the various places of life (as home and work) and finally urban sprawl. Moreover the speed necessary to ensure accessibility causes more accidents, pollutant emissions and fuel consumption.

As the metric of current road networks seems to have important undesirable spill over effects, we propose to simulate changes in the characteristics of an empirical road network (Zurich, Switzerland) and analyse their effects on accessibility and consequently on mobility practices of people. More specifically, we propose to revise downwards the permitted speed and to simulate, thanks to a multi-agents system (MATSim : www.matsim.org), the effects on mobility practices (travelled distances, transportation mode used, choice of places visited). At first we consider that all amenities (places of work, leisure, shopping) are fixed and then we combine the change of transportation speed with an optimal relocation process of amenities. The aim is to see if it is possible, in a sustainable development perspective, to go toward urban territories in which a good accessibility will be decoupled from automobile use.

The paper is organized as follows. We start with the presentation of the basics of MATSim, the multi-agent system that we used in order to simulate people behaviour and their reactions to car speed changes. Next, we present the results in terms of mobility practices that we obtained simulating car speed changes in the urban areas of Zurich. Next, we introduce the optimal relocation method of amenities and present the results of simulations which couple changes of speed and relocation of amenities process. Finally, we summarize the work presented, we provide some overall conclusions and present the future work agenda.

2. The basics of MATSim

MATSim is an agent based traffic simulator (Balmer et al., 2009). The actors of the modelled system (agents) are represented at individual level and act in an artificial environment, according to given rules, pursuing a given goal and having learning capabilities. The behaviour of the system “emerges” from the simulation as a consequence of individual agents’ behaviour. According to this paradigm, travel is the consequence of the need of persons to perform activities at different places. At the start of the simulation, each agent is located at his home. He has a list of activities to perform (a plan). For example, he has to go to work, then shopping and finally to a leisure activity before coming back home. All these plans correspond to the initial transportation demand, which has been created based on the Swiss Microcensus (Swiss travel diaries survey, ARE and BFS, 2011). During the simulations, each agent tries to optimize its plan which has a total fixed duration, through a trial and error process. He can for example change its route, its mean of transportation (car, public transportation, walk and bike), the schedules of its activity within a certain margin (for example shops must be open), and at last he can change the location of the leisure and shopping places (but not its home and place to work in a first step). For each iteration, a part of the agents – this is typically set to 10% but can be changed - is allowed to modify their plan trying to maximize their individual utility. The utility of a plan (based on Charypar, D. and K. Nagel, 2005) corresponds to the sum of the utilities of the performed activities Uact,i minus the disutility associated with travel (transportation cost) Utrav,i

$$U_{plan} = \sum U_{act,i} \left(type_i\, , startt_i, dur_i\right) + \sum U_{trav,i} \left(loc_{i-1} - loc_i\right) \qquad (1)$$

With $type_i$: the type of the performed activity; $start_i$, the start time of the activity and dur_i its duration. A score is assigned to each executed plan according to the utility provided to the agent who will try to keep the plans with the better scores and discard the worse during the process. It should be noted that transportation duration take into account interactions with other agents, which can lead to a high density of traffic and even traffic jams. So, travel times can diverge even substantially from free-flow travel times.

3. The simulations

The simulations are done for the “Zurich-greater area” which represents an area obtained drawing a circle that has as centre Bellevueplat in Zurich city centre, and a radius of 30km. There are 16181 agents that correspond to 1% of the population of the zone. Therefore, the capacities of the network have been scaled down according to this population in order to have realistic simulations. The road network of Zurich counts 22237 km and has 163235 arcs (every link represents only one direction in the network), with 422 km of roads where the maximum speed is greater than or equal to 90 km/h and 16067 km with speeds under 50 km/h. The remaining speeds vary between 55 and 80 km/h (5747 km).

Starting from this network, we simulate for the first scenario a reduction of 30% of the current speed (slow network) and for the second scenario a homogenization of the speed (homogenized network) according to the Table 1.

Table 1. Speeds limits on the three networks used in the simulations.

Normal Speed Limit	Reduced Speed Limit (30%)	Homogenization (H)
15	15	15
20	15	20
30	21	30
35	24.5	40
40	28	45
45	34.5	50
50	35	50
55	38.5	50
60	42	55
65	45.5	55
70	49	60
80	56	65
90	63	70
100	70	70
120	84	80

The first scenario corresponds to a current trend of urban planning of reducing speed in order to improve safety, to limit pollutant emissions and energy consumptions, to improve the relative efficiency of non-automobile modes and, in a spatial-temporal-planning perspective, to force people to choose their places of lives according to their physical proximity and not only according to their temporal proximity.

As we saw in the introduction that the hierarchy by speed in the road networks leads to undesirable spill-over effects, we simulate a homogenization of the speed in order to tend towards a more homogeneous distribution of the flows because the betweenness centrality of the arcs will be more spread (Penn and al., 1998).

For these two scenarios, the simulations are done for 16181 agents. The mode choice and the location choice of MATSim can, or not, be enabled. According to these choices, an agent can (or not) change its mean of transportation and/ or the facility he visited to perform a given activity in order to maximize its utility. When the location choice is enabled an agent can change its places of shopping and / or leisure but not its home or place of work.

For the following simulations, mode choice and location choice are enabled for shopping in grocery shops and leisure activities. There are 100 grocery shops and 2460 agents which have this activity in their plan.

Table 2 shows the modal split for all the population and only for agents doing grocery shopping for three networks.

Table 2. Modal split for all agents and for agents doing grocery shopping.

Network	Mode			
	Car	Bike	Walk	Public transport
	All the agents (16181)			
Normal speed	56.28%	5.32%	23.49%	14.89%
Reduced speed	54.28%	5.51%	25.11%	15.08%
Homogenized	56.22%	5.31%	23.54%	14.92%
	Agents doing grocery shopping (2460)			
Normal speed	69.22%	4.14%	10.96%	15.66%
Reduced speed	67.47%	4.77%	11.11%	16.63%
Homogenized	69.07%	4.58%	10.85%	15.47%

As expected, it appears that changes of speed limits reduce the number of people taking the car, but also that this change in modal split is low: 2.00% for all the population and 1.75% for agents doing grocery shopping. In both cases agents switch to walk, but also to other modes since they were not affected by the reduction of the speed limit. We can also notice that the homogenized network has almost no impact on the modal split.

However, if we focus on the distance travelled by each mode to do grocery shopping (Table 3) it appears that the two simulated scenarios cause a reduction of the travelled distance. Indeed, the reduction of the speed limits forces agents to do their grocery shopping at closer locations in order to make up for the reduction of speed limit. As a consequence, the mean distance travelled for shopping for all modes decreases: -10.9% for the slow network and -6.1% for the homogenised network. We observe the same for all the trips (Table 4), but the decrease is lower because the location choice is enabled for grocery shopping and leisure activities, but not for non-grocery activities.

It must be mentioned here that only distances by car are calculated based on the length of links that the car pass through, while other modes distances are calculated based on the bee-line distance between origin and destination.

Table 3. Average distance travelled by each mode to do grocery shopping activity (in meters).

Network	Mode				
	Car	Bike	Walk	Pt	All
Normal speed	6935	1394	1876	3341	5588
Reduced speed	6107	1475	2125	3334	4982
Homogenized	6445	1446	1960	3337	5248

Table 4. Average distance travelled for all the trips by each mode (in meters).

Network	Mode				
	Car	Bike	Walk	Pt	All
Normal speed	11697	1976	1654	6755	8083
Reduced speed	11408	1931	1769	6720	7757
Homogenized	11033	1895	1694	6787	7716

If we focus now on the travel time (Table 5 and Table 6) we can logically see that they increase for the slow network for grocery activity (+16.9%) as well as for travel time for all plans (+16.9%). However, for the homogenised network, the situation is more complex. Indeed the travel times are almost unchanged when all modes and all trips are considered (+3.4 %), while they decrease of 1.1% when we just consider trips to do grocery shopping, although the speeds for this network are lower than the current speeds.

The reason is that for homogenized network the chosen locations to do grocery shopping and leisure activities by agents are closer. This is also the case for the slow network, but for homogenized network the changes of shopping and leisure places provides better compensation for such a substantial decrease in speed.

Table 5. Average travel time for all trips by mode (in seconds).

Network	Mode				
	Car	Bike	Walk	Pt	All combined
Normal speed	684.44	711.82	1656.68	1764.83	1075.27
Reduced speed	938.67	695.82	1771.19	1754.81	1257.48
Homogenized	733.13	678.93	1697.01	1775.79	1112.76

Table 6. Average travel time for the trips to grocery shopping activities (in seconds).

Network	Mode				
	Car	Bike	Walk	Pt	All combined
Normal speed	464.11	603.94	1875.89	995.82	708.01
Reduced speed	587.57	639.00	2124.82	993.79	828.48
Homogenized	465.36	626.39	1959.97	994.56	716.89

To appreciate the respective role of change in speed and change in location choice, we ran the simulations for the three networks, but now with disabled location choice module, that is to say that the transportation conditions are changed, but agents can no more adapt their behavior through the choice of shopping and leisure places which are given. In this case, travel time increase of 16% for the slow network and of 1.8% for the homogenized network. It shows that the decrease in travel time and distances for the homogenized network is effectively caused by the change of shopping and leisure locations.

Regarding the scores of the plans (Table 7), it appears that they drop for the slow network (-2.7% regardless of agents having grocery shopping in their plans or not), but that they are quite stable for the homogenized network because the change in shopping and leisure activities location makes up for the reduction of speed on the main infrastructures.

Table 7. Score statistics of all executed plans.

Network	Score Statistics	
	Average	Standard Deviation
Normal speed	131.08	63.07
Reduced speed	127.57	64.30
Homogenized	130.35	63.00

This first set of simulations suggests that speed policies may help to tend toward a modal split in favor of non-automobile modes but that their effects remain modest, even for a vigorous policy (decrease of the speed of 30%). In contrast the effects of speed policies appear more important to reduce travelled distances as they encourage people to choose visited locations according to a physical proximity logic, rather than on a temporal proximity.

Here, a decrease of the speed on the whole road network doesn’t seem to be a good solution as the decrease in travelled distances goes with an increase in time distance and a decrease of the satisfaction of people, which might be difficult to accept for people and therefore difficult to actually implement. On the contrary, a homogenization of the speed limits, seems to be more suitable as it allows both to reduce travelled and time distances but to maintain people’s satisfaction at the same time, thanks to changes in their spatial-temporal plans.

Therefore, a homogenized network appears to be more “flexible” than a slow network to give people the capacity to optimize their activities program.

To go further than these first results we try in a second part to see if it is possible to tend both towards a better modal split without any decrease of individual utility and to minimize the travelled distances (and so the energy consumption, pollutant emissions etc. in a sustainability perspective) by coupling the change of speed with a relocation process of amenities.

The idea is to consider a given mobility pattern (the current one or the ones observed for the simulated networks). Then we use an optimal relocation method to find new locations for amenities in order to minimize the total transportation time distance (rather than the travelled distance, because people used to organize their activities according to a temporal optimization process). Once the optimal location is found they are used as an input to a new simulation in MATSim, to analyze their effects on mobility practices.

For this paper, we aim at relocating first only grocery shops, and then 15% of all the amenities (shops, house, jobs and leisure). This is similar to what has been done in a previous study (Ciari and Axhausen, 2012), also using MATSim, where the focus was on finding optimal location for retailers based on agents’ activities.

4. Relocation process

At the end of a MATSim simulation an evaluation of the flows (i.e the number of moves) between couples of a given set of amenities is considered. This set includes homes, leisure places, working places and shops. For tractability reasons, explained by the large number of possible home (or jobs, leisure,...) locations, a clustering step is done previously in order to group similar amenity types and thus reducing their numbers from total number of facilities (372164) to 1276 clusters.

At first, we are interested in relocating:

- only grocery shops
- both grocery shops and leisure facilities

Then, between each couple of amenities of the plans of the agents the average trip times, are computed. In summary, at the end of the steps above, we have a reduced set of amenities, flows values and average trip time values between each couple.

We measure the *“quality”* of facility locations by the overall trip time between all amenities (i.e the sum of all trip times). Notice that our methodology is independent of the *“measure”* used that may be fit differently (it is for example possible to work with the travelled distances rather than the time distance). The associated combinatorial optimization problem consists in finding the suitable shop locations minimizing the overall trip time. This is actually a variant of the well-known Quadratic Assignment Problem introduced by Koopmans and Beckmann (1957). An heuristic method, using a greedy algorithm, is applied to obtain a good feasible solution (not necessarily optimal). The new locations are then plugged into MATSim, simulated again, and the whole process is iterated until reaching a stopping criteria (maximal number of iterations, difference of two successive overall trip times lower than a given threshold).

In a second set of simulations we consider simultaneously all the types of amenities and not only the shops and leisure facilities. Here we try to find the best solution to minimize the overall trip time for the different networks, by considering that it is possible to change the location of 15% of amenities (work, leisure, home, shops) and that the location are permutable.

After the initial simulations (the ones in the first part of this paper), each simulation was restarted for another set of iterations, with and without the relocation of facilities. This way, we can make a more accurate comparison and see the impact of the relocation process.

In Table 8, 9 and 10 we can see the results of the relocation process for the slow and homogenized networks for the different relocation scenarios. At first it appears that relocating only grocery stores and, to a lesser extent, relocating both grocery and leisure facilities doesn’t change deeply the situation for the score, the modal split and travel times (we can just notice a slight improvement of the scores when relocating both grocery and leisure facilities).

On the other hand, relocating 15% of all amenities, for the slow and the homogenized networks, causes important and suitable changes which provide more sustainable mobility, particularly for the homogenised network.

Indeed we can notice an increase in the scores, a decrease in car use and travel time. For example, the maximum score (135.20) is obtained for the homogenized network with relocation of amenities and represent an increase of 3.2% compared to the network without speed reduction and of 3% compared to the situation for the homogenized network without relocation. The decrease in car use and travelled distance is around 4% for the two simulated networks with relocation.

Increase in people utility, decrease of travel time and car use, all these findings tend to prove that it is possible to tend toward a slow but accessible city by acting simultaneously on the road network (the speed) and the locations of amenities. Therefore, accessibility can be decoupled from speed and car use.

Table 8. Score statistics for different scenarios with a reduced speed limit of 30% on the whole network and for the homogenized network.

Scenario	Score Statistics	
	Average	Standard Deviation
	Reduced speed (30%)	
No relocation	128.58	62.84
Grocery stores	128.53	62.79
Grocery/leisure	129.22	63.57
15% of all	132.26	62.48
	Homogenized network	
No relocation	131.25	63.66
Grocery stores	131.27	63.82
Grocery/leisure	132.03	64.40
15% of all	135.30	63.23

Table 9. Modal split for different scenarios with a reduced speed limit of 30% on the whole network and for the homogenized network.

Scenario	Mode			
	Car	Bike	Walk	Pt
	Reduced speed (30%)			
No relocation	54.45%	5.00%	25.93%	14.60%
Grocery stores	54.68%	5.08%	25.68%	14.54%
Grocery/leisure	54.61%	5.05%	25.38%	14.94%
15% of all	50.51%	6.25%	26.34%	16.88%
	Homogenized network			
No relocation	56.54%	4.73%	24.20%	14.51%
Grocery stores	56.58%	4.85%	24.02%	14.55%
Grocery/leisure	56.60%	5.06%	23.64%	14.68%
15% of all	52.21%	6.22%	24.83%	16.72%

Table 10. Travel times for different scenarios with a reduced speed limit of 30% on the whole network and for the homogenized network (in seconds).

Scenario	Mode				
	Car	Bike	Walk	Pt	All
	Reduced speed (30%)				
No relocation	952.30	686.93	1702.59	1769.74	1253.03
Grocery stores	952.05	711.21	1737.81	1786.97	1263.11
Grocery/leisure	977.85	754.11	1851.30	1775.84	1307.50
15% of all	896.72	717.03	1727.96	1411.04	1191.29
	Homogenized network				
No relocation	742.80	660.13	1706.50	1787.20	1123.77
Grocery stores	745.05	715.04	1723.56	1785.57	1133.28
Grocery/leisure	777.08	742.34	1782.08	1784.17	1160.85
15% of all	698.73	676.39	1552.88	1352.53	1018.83

5. Summary and future work

The results presented in the first part of the paper indicate that the reduction of speed limit by 30% in Zurich area, induces various effects: a) modal split shift from car to other modes b) decrease in distance travelled, as agents try to find closer locations for shopping and leisure activities, c) an increase in travel time and consequently a decrease of the scores of agents. Obviously, point a) and b) are, in the context of sustainable transportation, positive impacts while c) is an undesired effect. For the homogeneous network, it appears that the modal split is unchanged and the scores are nearly the same. However, average travel time slightly increases and distance travelled falls significantly, therefore agents are able with this type of network to perform activities at closer locations in good conditions of accessibility. Nevertheless, the impacts of the change in speed seem insufficient to go toward a more sustainable form of accessibility. They must be accompanied by an action on amenities location.

By coupling change in transportation speed and a relocation process, we showed in the second part of the paper that it is possible to have both a reduction of speed limits (and so of fuel consumption, pollutant emissions …) and to maintain the level of accessibility.

The more favorable configuration is obtained for a network with a homogenization of the speed coupled with a relocation of 15% of all facilities.

Here, the plans executed by the agents show a substantial increase in utility, not only making up for the reduction in speed, but having even higher scores than with normal speed limits. Moreover, car usage drops, while travel time decreases by 6% compared to the scenario with homogenized speed and no relocation of facilities. In addition, average travel time is now lower than for the network with normal speed limits.

Therefore, we can conclude that the relocation of facilities increases the utility of agents, triggers modal split changes in favor of modes different than car and provides better accessibility throughout the network.

To achieve the objective of accessible urban areas without a car use – that is, a slow but accessible city - this work will continue in different directions :

- Beyond the simulated network, we will test the effects on other types of networks, in particular more connective networks which are supposed to be intrinsically more favorable to walking and bicycling. We will also test more innovative metrics, as for example the slow metric we developed in another context (Genre-Grandpierre, Banos 2012).
- We will also work on the utility function used in MATSim both to increase its sensitivity to transportation costs, and to adjust it for different categories of agents according to the value of time.
- We will study whether it is possible to reach an optimum between change in speed, percentage of amenities to have to relocate and results in terms of sustainable mobility.

- At last, we will focus on working on larger scenarios – simulating all, or a larger part of the agents of a scenario instead of 1% as in the present study – and, if possible, on different cities, to verify the impact of speed reduction and facilities relocation for different spatial contexts.

References

ARE and BfS (2011) Mobilität in der Schweiz, Ergebnisse des Mikrozensus 2010 zum Verkehrsverhalten, Bundesamt für Raumentwicklung; BFS Statistik der Schweiz, Neuchâtel.

Balmer, M., M. Rieser, K. Meister, D. Charypar, N. Lefebvre and K. Nagel (2009b) MATSim-T: Architecture and simulation times, in A. L. C. Bazzan and F. Klügl (eds.) *Multi-Agent Systems for Traffic and Transportation Engineering*, 57–78, Information Science Reference, Hershey.

Charypar, D. and K. Nagel (2005) Generating complete all-day activity plans with genetic algorithms, Transportation, 32 (4) 369–397.

Ciari, F. and K.W. Axhausen (2012) Modeling Location decisions of retailers with an agent-based approach, paper presented at the *91st Annual Meeting of the Transportation Research Board*, Washington, D.C., January 2012.

Foltête J.C., Genre-Grandpierre C., Josselin D., 2011 : “Impacts of Road Networks on urban mobility”, in Theriault M., Des Rosiers F (ed) *Modeling urban Dynamics*, Geographical Information systems series, ISTE, Wiley, pp. 103-128.

Genre-Grandpierre C., Banos A. 2012 : “Toward new metrics for urban road networks : some preliminary evidence from Agent-based simulations”, in Heppenstall, A.J.; Crooks, A.T.; See, L.M.; Batty, M. (Eds.) *Agent-Based Models of Geographical Systems*, Springer.

Geurs K.T., Ritsema van Eck J.R. (2001). *Accessibility measures : review and applications. Evaluation of accessibility impacts of land-use transportation scenarios, and related social and economic impact,* Rijksinstituut voor Volksgezondheid en Milieu RIVM,

Gutiérrez J., Monzòn A., Pinero J.M (1998). «Accessibility, network efficiency and transport infrastructure planning». *Environment and Planning A*, 30, p. 1337-1350.

Hägerstrand, T. (1989) Reflections on “What about people in regional science?”, Papers of the Regional Science Association, 66, 1–6.

Levinson D., Kumar A. (1994). «The rational locator : why travel times have remained stable», *Journal of the American Planning Association* 60(3), p. 319-332.

Penn A., Hillier B., Xu J. (1998). «Configurational modelling of urban movement networks», *Environment and Planning B,* 25, p. 59 – 84.

T. C. Koopmans and M. J. Beckmann. Assignment problems and the location of economic activities. Econometrica, 25:53–76, 1957.

Wiel M. (2002). *Ville et automobile*. Paris, Descartes et Cie, 140 p.

Zahavi Y., Talvitie A., 1980, Regularities in Travel Time and Money Expenditure, *Transportation Research Record,* 750, 13-19.