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Oussama Saoudi Hassani
Nicolas Saunier
Catherine Morency

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Optimization Scenarios of Home-Work Distances in Montreal

Oussama Saoudi Hassani[1,*], Nicolas Saunier[1,2], Catherine Morency[1,2]

[1] Department of Civil, Geological and Mining Engineering, Polytechnique Montréal, P.O. Box 6079, Station Centre-ville, Montréal, Canada H3C 3A7

[2] Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT)

Abstract. In Montreal (Canada), traffic congestion during peak hours is mainly caused by commuting. Many authors argue that a more effective management of car commute trips could help improve the situation. This paper presents optimization scenarios of home-work distances in the Greater Montreal Area (GMA). The objective of this theoretical exercise is to assess the maximum reduction in home-work distances that could result if workers based their home location on the "best choice" for commuting. By combining data from the 2008 Origin-Destination (OD) survey and the 2011 National Household Survey (NHS), it is possible to assess the effectiveness of relocalizing households. Three scenarios minimizing total home-work distances are investigated: S1) reallocation of car-commuters while accounting for household size, S2) reallocation of car-commuters while accounting for household size and house-type and S3) reallocation of car-commuters while accounting for household size, house-type and tenure type (owned or rented dwelling). All scenarios are estimated at the municipal level. Moving workers to other home locations based on S1 reduces home-work distances by 58 %, to 4,743,577 pers-km, down from 11,308,574 pers-km. As real travel distance between home and work are at least twice this distance, this represents a very important reduction. S2 reduces home-work distances to 5,424,141 pers-km: it is more restrictive but still accounts for a significant reduction potential. Finally, when estimating S3, the most restrictive scenario, total home-work distances are reduced by over 51 % (down to 5,718,749 pers-km). The paper examines the spatial structure of the results and provides ideas for policy implementation.

Keywords: Excess commuting, home-work distance, household survey, cost minimisation, scenarios.

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* Corresponding author: oussama.saoudi-hassani@polymtl.ca

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INTRODUCTION

Context

Most workers commute during peak periods, which increases road congestion during mornings and evenings (Anderson, M. 2014). This phenomenon may lead workers to drive less safely and thus increase the risk of accidents, but also creates anger, frustration and fatigue that have an impact on their work performance and physical health (Haider, M. et al. 2013). Not only does this congestion entail the deterioration of the intellectual and physical capabilities of most workers and consequently their ineffectiveness at work, but also a slowdown in economic development and a deterioration in the quality of life and the environment. In 2011, congestion caused losses estimated at 121 billion US dollars to 498 US urban areas (Schrank, D. et al. 2012). Of these losses, 63% are caused by congestion in peak hours (Schrank D. et al. 2012).

The Greater Montreal Area (GMA) suffers from traffic congestion problem during peak hours; this is mainly caused, as in any dense urban area, by commuter trips conducted in the region (Anthony, D. 2004). Traditional solutions to congestion, such as building new roads or expanding existing routes, are generally not effective or feasible. The increase in capacity required in order to significantly impact congestion is too expensive. Smarter and more sustainable actions are needed to improve traffic management. Alternative solutions can be adopted to mitigate this congestion.

Objective

The objective of this paper is to evaluate the optimization of home-work distance scenarios which could reduce the number of trips made by cars in peak hours. It develops a methodology to estimate the impacts of an optimal relocation of Montreal car-commuters close to their workplaces. It uses a novel process composed of three theoretical optimizations minimizing the distances separating workers' home locations from their respective workplaces. The optimizations are composed of three specific constraints: household size, house-type preference and housing tenure. The paper is organised as follows: a literature review is first presented. Then, the general methodology is described, including the definition of the analytical process and the three levels of constraints. The following sections present the results of the relocalization. The paper closes with a conclusion.

BACKGROUND

Excess commuting represents the difference between the actual average commuting distance and the shortest calculated one. The second is generally calculated by considering that workers choose their place of residence according to two factors: the minimization of their commuting distance and housing costs. The imbalance between the number of houses per area and the number of jobs in the same area may explain excess commuting (Cervero (1989), Sultana (2002), Sultana & Weber (2014) and Wang (2001)). The most relevant excess commuting studies were conducted by Hamilton (1982, 1989), White (1988), Cropper & Gordon (1991), Small & Song (1992) and Giuliano & Small (1993). (Kim (1993))

Hamilton (1982) optimized worker and home locations using a monocentric urban model and compared minimized commuting distances to actual average commuting distances. The difference between the two is designated as "wasteful commuting".

White (1988) asserts that Hamilton's approach is incorrect for two reasons: first, Hamilton does not consider the actual spatial distribution of homes and workplaces, and he does not consider the existing road network. White used a home-work trip matrix to optimize commuting journeys and linearly resolved the problem using commute time, instead of distance, as the problem variable.

Small and Song (1992) proved that using the spatial dimension as a variable for the optimization gave different results than considering the temporal dimension. Indeed, they computed two optimizations using the same data and used the spatial approach developed by Hamilton for one and the temporal model developed by White for the other. They obtained different results for each approach. They renamed wasteful commuting as excess commuting.

Cropper and Gordon (1991) used house-type and neighborhood preference as well as housing tenure, as constraints for the optimization. They also computed the optimization for one and two-worker households. They proved that taking all the constraints into consideration and accounting for the second worker reduced excess commuting.

Giuliano and Small (1993) considered that there is an imbalance when the residential capacity of a sector is different from the number of workers in the same sector. They stated that workplace location does not influence the choice of home location. Indeed, households can be composed of more than one worker, and other parameters, such as house-type or neighborhood preference could be more important when choosing home location.

GENERAL METHODOLOGY

Process

Figure 1 provides the constraints used in each of the three scenarios. The process is composed of three theoretical optimizations minimizing the distances separating the workers' home locations with their respective workplaces. The optimizations aim to reduce the average commuting distance in the Greater Montreal Area by redistributing households into existing housing.

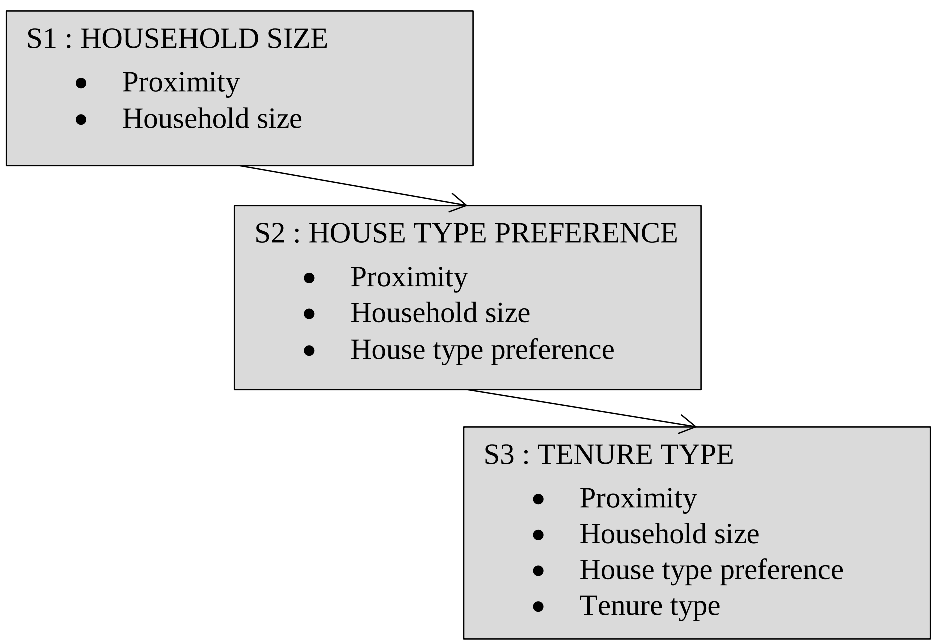

Figure 1: Theoretical optimizations

For the first optimization (S1), only household size is used as a constraint to relocate workers. For multi-worker households, household total commuting distance is minimized. Figure 2 illustrates the process.

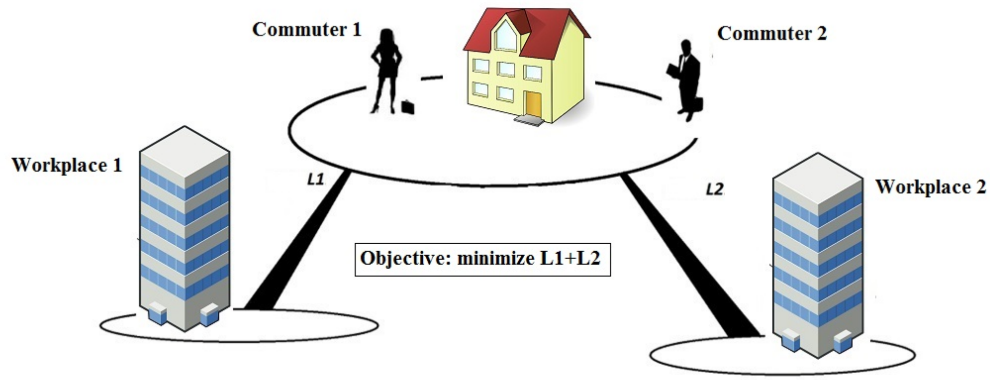

Figure 2: Minimizing of total household commuting distance

The following optimization (S2), adds house-type preference to household size as a constraint. House-type preferences are obtained with the 2011 National Household Survey (NHS). This means that if in the optimization (S1), a household used to live in a "townhouse" for example, the optimization ensures that the household is theoretically relocated to a sector that also has the same type of dwelling. The optimization is conducted at a macroscopic scale due to the lack of data at the individual level.

The last optimization (S3) takes into consideration the first two optimization constraints as well as tenure type: renter or owner.

Model

A cost minimization model was developed. The model aims to minimize the total daily home-work commuting distance of a household in which workers commute by car. It aims to minimize Z, the total cost (in kilometers):

$$Z = \sum_{ij} C_{ij}.X_{ij} \ \forall i,j$$

With:

i : Municipal sector of workers' home location

j : Municipal sector of workers' workplace

Cij : Cost in km associated to the Euclidian distance between the centroid of the municipal sector of origin and that of destination

Xij : Number of workers living in i and working in j

The optimization was conducted at the municipal sector scale because of a lack of data on individual house-type preferences. The commute distance is calculated as the Euclidian distance between the centroid of the municipal sector of origin and that of destination. In the case of the Greater Montreal Area, the actual average commute distance is 13.36 km and amounts to 12.9 km on average using our simplified approach. Our approach slightly underestimates commuting distances.

EXPERIMENTAL RESULTS

Optimization (S1): Household size

For this optimization, only the household size is used as a constraint to relocate workers, the following approach is applied:

1. Obtain the Origin-Destination matrices Xij of workers residing in i and working in j
2. Compute the Cij matrix
3. Solve the commuting distance minimization problem

The approach is illustrated by a simple example in Figure 3:

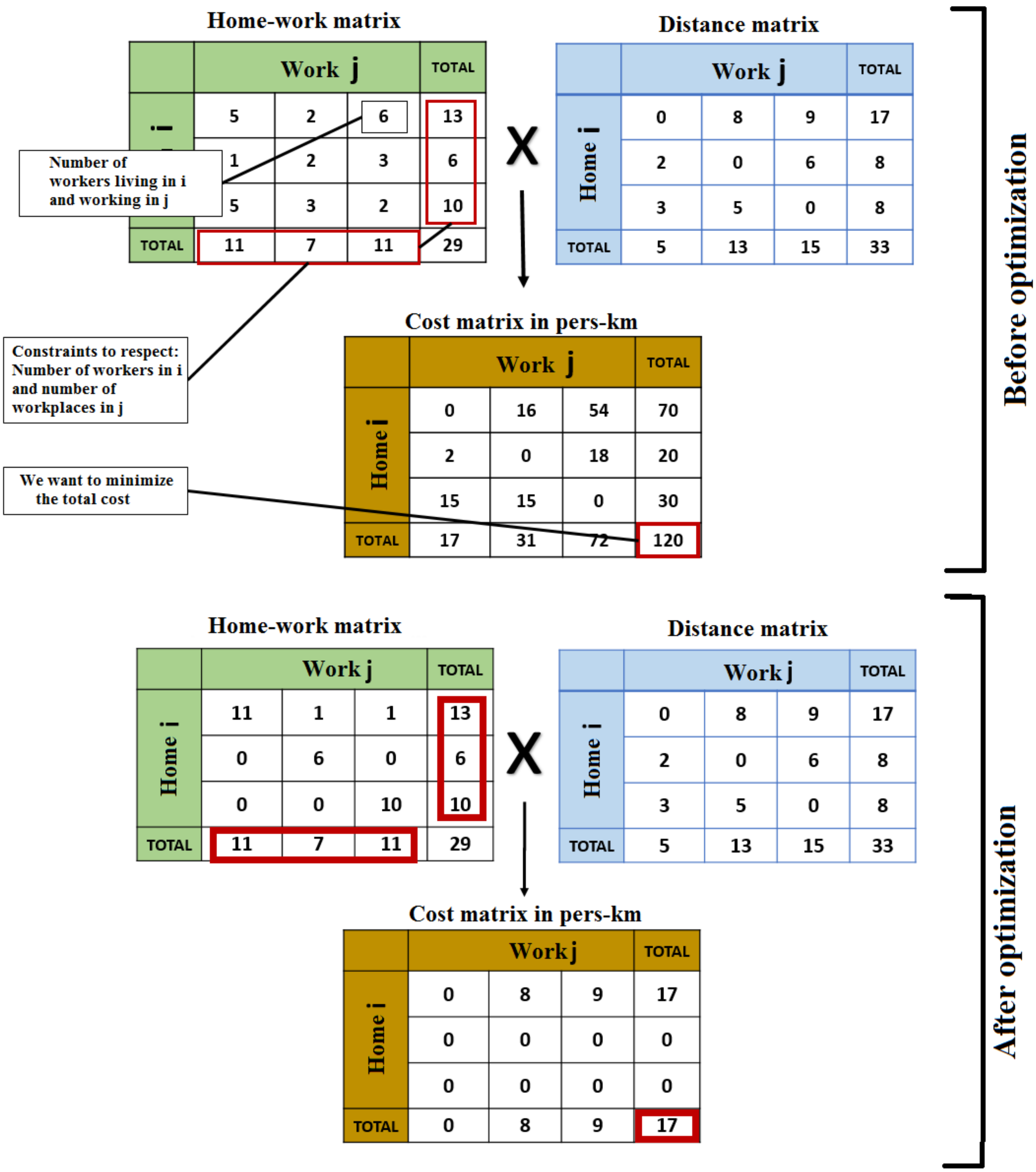

Figure 3: A simple example of a matrix of 3x3 municipal areas

A 108*108 dimensions matrix was used for the optimizations, corresponding to the Greater Montreal Area's 108 municipal sectors. It is composed of 11 664 variables. Opensolver was used to solve the model. Table 1 and Table 2 show the results. Initial and optimized average daily commuting distances are obtained with the ratio (∑pers–km)/(∑ pers) for each household size category. The cost savings are calculated by subtracting optimized costs from initial costs.

Table 1 Initial and optimized commuting cost in pers-km (S1)

Household size	Initial cost (pers-km)	Optimized cost (pers-km)	Savings (pers-km)	Savings (%)
1p	991375	342977	648398	65 %
2p	3537492	1398272	2139221	60 %
3p	2741799	1156253	1585546	58 %
4p	2801675	1278238	1523437	54 %
5p	940229	439908	500321	53 %
6p and more	296004	127928	168075	57 %
Total	11308574	4743577	6564998	58 %

Table 2: Initial and optimized average commuting distance in km (S1)

Household size	Initial distance (km)	Optimized distance (km)	Savings (km)	Savings (%)
1p	**11.6**	**4.0**	**7.6**	**65 %**
2p	**12.9**	**5.1**	**7.8**	**60 %**
3p	**13.0**	**5.5**	**7.5**	**58 %**
4p	**13.0**	**5.9**	**7.1**	**54 %**
5p	**12.9**	**6.0**	**6.9**	**53 %**
6p and more	**12.8**	**5.5**	**7.3**	**57 %**
Total	12.9	5.4	7.5	58 %

This optimization saved **6 564 998 pers-km** per day and reduced the average daily commuting distance by **7.5 km**. This means that relocating Montreal workers close to their workplace would reduce the average commuting distance by more than **58 %**.

Optimization (S2): Household size and house-type preference

This optimization adds house-type preferences to household size as a constraint. House-type preferences are obtained from 2011 NHS. The following approach is applied, using 30 OD matrices (5 house-type categories x 6 household size categories):

1. Allocate households in a municipal sector to their corresponding house-type category according to their size.
2. Minimize the commuting distance for each household size category according to their house-type preference.
3. Estimate the total commuting cost.

The 2011 NHS contains the distribution of households by house-type and household size category by census tract. Using a probability model based on the NHS data, a house-type is assigned to households in the 2008 OD survey using household size and location attributes.

Example:

1- According to the 2011 NHS, 30 % of three-person households in sector A live in a duplex.

*2- According to the 2008 OD survey, 300 three-person households live in sector A. We can estimate that 90 three-person households live in a duplex in sector A: 300*30 % = 90.*

N.B: A spatial join was necessary to associate the census tracts of the 2011 NHS with the municipal sectors of the 2008 OD survey.

To simplify the model, we combined some of the house-type categories defined in the 2011 NHS. This reduced the number of categories down from eight to five, as follows:

- Type i: Single-detached house
- Type ii: Apartment in a building that has five or more storeys
- Type iii: Duplex or Apartment in a building that has fewer than five storeys
- Type iv: Semi-detached or row house
- Type v: Others (movable dwelling or other single-attached house)

Tables 3 and 4 below show the results. Initial and optimized average commuting distances are obtained with the ratio $(\sum \text{pers–km})/(\sum \text{pers})$ for the different household size categories. The cost savings are calculated by subtracting optimized costs from initial costs.

Table 3: Initial and optimized commuting cost in pers-km (S2)

Household size	Initial cost (pers-km)	Optimized cost (pers-km)	Savings (pers-km)	Savings (%)
1p	991029	417789	573239	58 %
2p	3553154	1618921	1934233	**54 %**
3p	2736073	1313978	1422095	52 %
4p	2796925	1432726	1364199	49 %
5p	939465	489562	449903	48 %
6p and more	291927	151164	140763	48 %
TOTAL	11 308 574	5 454 141	5 884 433	52 %

Table 4: Initial and optimized average commuting distance in km (S2)

Household size	Initial distance (km)	Optimized distance (km)	Savings (km)	Savings (%)
1p	**11.7**	**4.9**	**6.8**	58 %
2p	**12.9**	**5.9**	**7.0**	54 %
3p	**13.0**	**6.3**	**6.8**	52 %
4p	**13.0**	**6.7**	**6.3**	49 %
5p	**12.9**	**6.7**	**6.2**	48 %
6p and more	**13.0**	**6.7**	**6.3**	48 %
TOTAL	12.9	6.2	6.7	52 %

This optimization saved **5 884 433 pers-km** per day and reduced the average daily commuting distance by **6.7 km**. This means that relocating Montreal workers close to their workplace would reduce the average commuting distance by more than **52 %**. Moreover, results show that the type iii (duplex or apartment in a building that has fewer than five storeys) is the house-type that benefits from the largest reduction in commuting cost. This could mean that workers living in this type of house are poorly spatially organized in relation to their workplaces.

Distribution (S3): Household size, house-type preference and tenure type

This optimization adds tenure type to the house-type preference and household size constraints. The tenure type is obtained from the 2011 NHS. The following approach is applied, using 60 OD matrices (5 house-type categories x 6 household size categories x 2 tenures types):

1. Allocate households of a municipal sector to their corresponding tenure type depending on their house-type and their size.
2. Minimize the commuting distance for each household size category according to their house-type preference and tenure type.
3. Estimate the total commuting cost.

Tables 5 and 6 below show the results. Initial and optimized average commuting distances are obtained with the ratio (∑pers–km)/(∑ pers) for the different household size categories. The cost savings are calculated by subtracting optimized costs from initial costs.

Table 5: Initial and optimized commuting cost in pers-km (S3)

Household size	Initial cost (pers-km)	Optimized cost (pers-km)	Savings (pers-km)	Savings (%)
1p	983141	517722	465419	47 %
2p	3512126	1657762	1854364	53 %
3p	2722547	1325845	1396701	51 %
4p	2868701	1448011	1420690	50 %
5p	933187	490238	442949	47 %
6p and more	288872	150245	138627	48 %
TOTAL	11 308 574	5 589 825	5 718 749	51 %

Table 6: Initial and optimized average commuting distance in km (S3)

Household size	Initial distance (km)	Optimized distance (km)	Savings (km)	Savings (%)
1p	9.3	4.9	4.4	47 %
2p	12.9	6.1	6.8	53 %
3p	13.0	6.4	6.7	51 %
4p	13.0	6.5	6.3	50 %
5p	12.9	6.8	6.1	47 %
6p and more	13.0	6.8	6.2	48 %
Total	12.9	6.2	6.7	51 %

This optimization saved **5 718 749 pers-km** per day and reduced the average daily commuting distance by **6.4 km**. This means that relocating Montreal workers close to their workplace would reduce the average commuting distance by more than **51 %**. Moreover, results show that for most household size categories, renters of type ii (apartment in a building that has five or more storeys) and owners of type iv (semi-detached or row house) reduced their commuting distance the most. Also, because owners of type iii houses (duplex or apartment in a building that has fewer than five storeys) reduced their commuting distance by only 1 % after the optimization, we can assume that they are already well located in relation to their workplaces.

RESULT ANALYSIS

First, the distribution of workers depending on their commuting distances before and after the optimizations is analyzed. Then, a spatial analysis is conducted to identify areas that are subject to the most important changes.

Distribution of workers according to commuting distances before and after optimizations are conducted

Figure 4 shows the distribution of workers according to the initial baseline scenario and the results of the three optimization models. In the baseline scenario, the number of workers decreases almost linearly with the commuting distance. After the last optimization, the commuting distance is considerably decreased: over 63 % of workers are relocated to within 5 km of their place of employment.

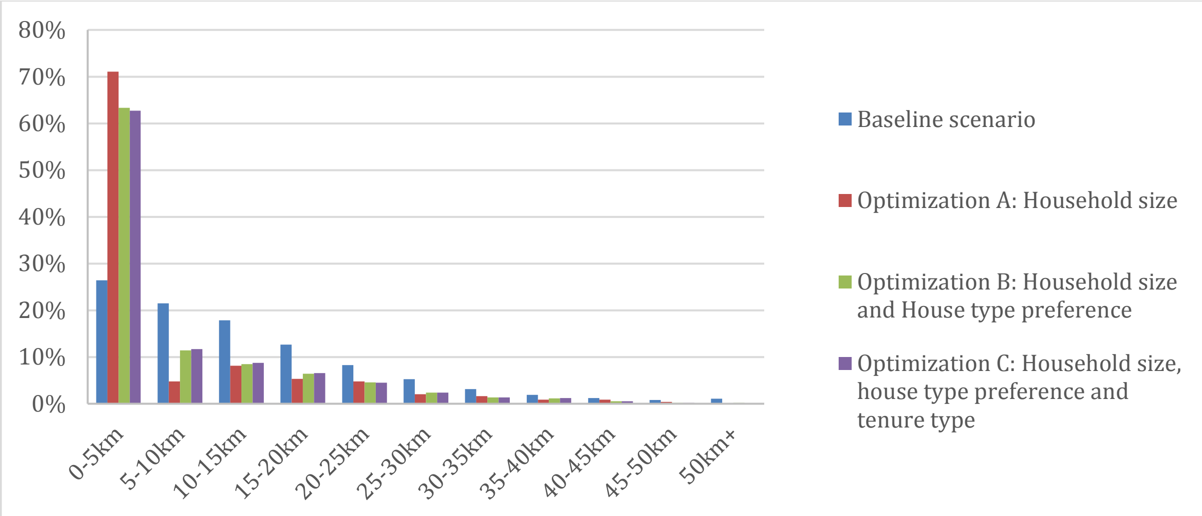

Figure 4: Distribution of workers according to commuting distances before and after optimizations

Spatial analysis

A spatial analysis by area of residence shows those most affected by the optimizations. Figure 5 shows that, for car commuters, the average daily commuting distance decreases in all sectors of the Greater Montreal Area. The new residents of the center of the Island of Montreal, of Longueuil and of Laval-Pont-Viau are those with the largest reduction in their commuting distances after the optimizations.

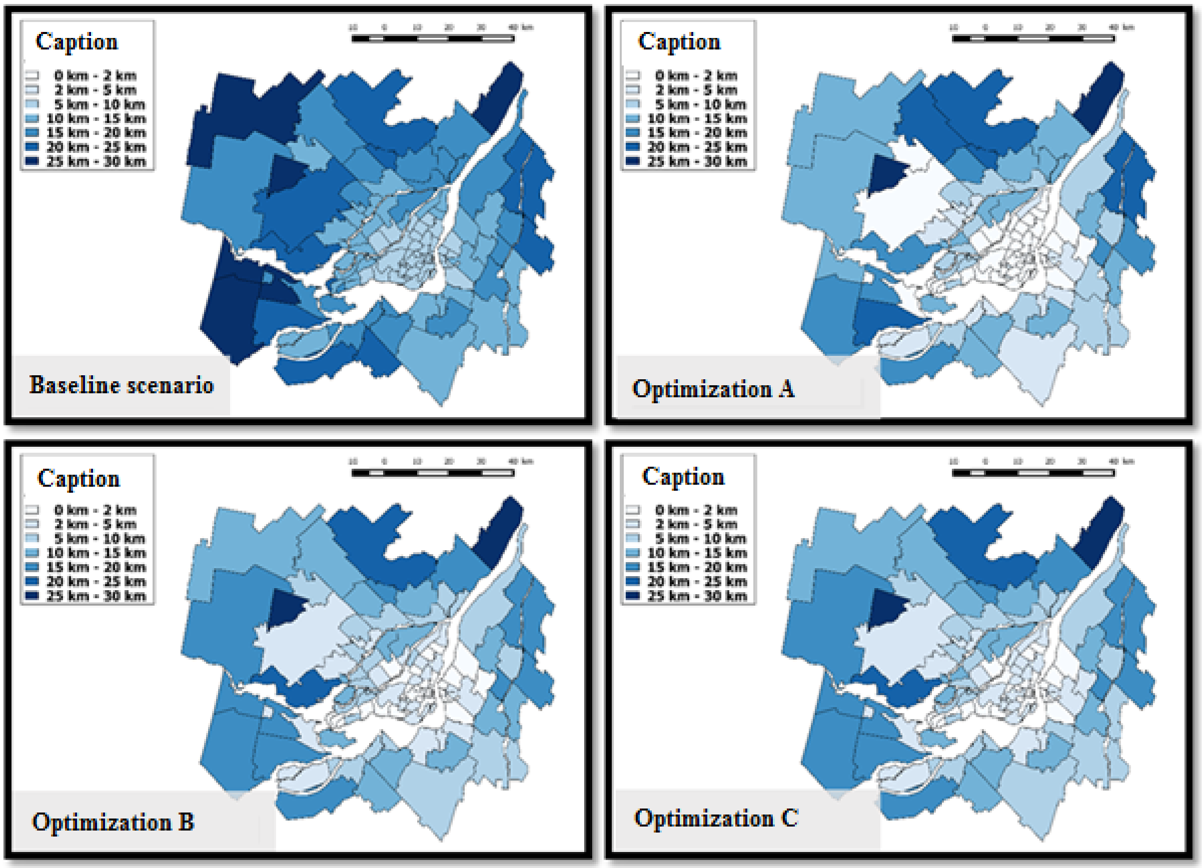

Figure 5: Average commuting distance, in km, according to the municipal sector of residence before and after optimizations

PROPERTY COST

The results show there is a potential for reducing commuting distances in Montreal. However, the approach used in this study is based only on commuting distances. Several other parameters may be added to the model, such as property cost, commute time, neighborhood preference, etc. These parameters could have an important effect on the choice of place of residence. Of these, the property cost parameter is investigated in the following.

According to the distribution of property costs in the 2006 Canadian Census of Population, the average value of a property varies across the Greater Montreal Area. This might be a barrier to relocate workers close to their workplaces. To evaluate the importance of the property cost parameter, an analysis of the difference in the average housing unit cost between the baseline scenario and S3 was conducted.

Figure 6 shows the average housing unit cost difference between the baseline scenario and S3 as a function of the commuting distance difference between the baseline scenario and the S3. Each bubble represents one of the 108 municipal sectors of the Greater Montreal Area (GMA). The area of each bubble represents the proportion of households in the GMA living in the sector.

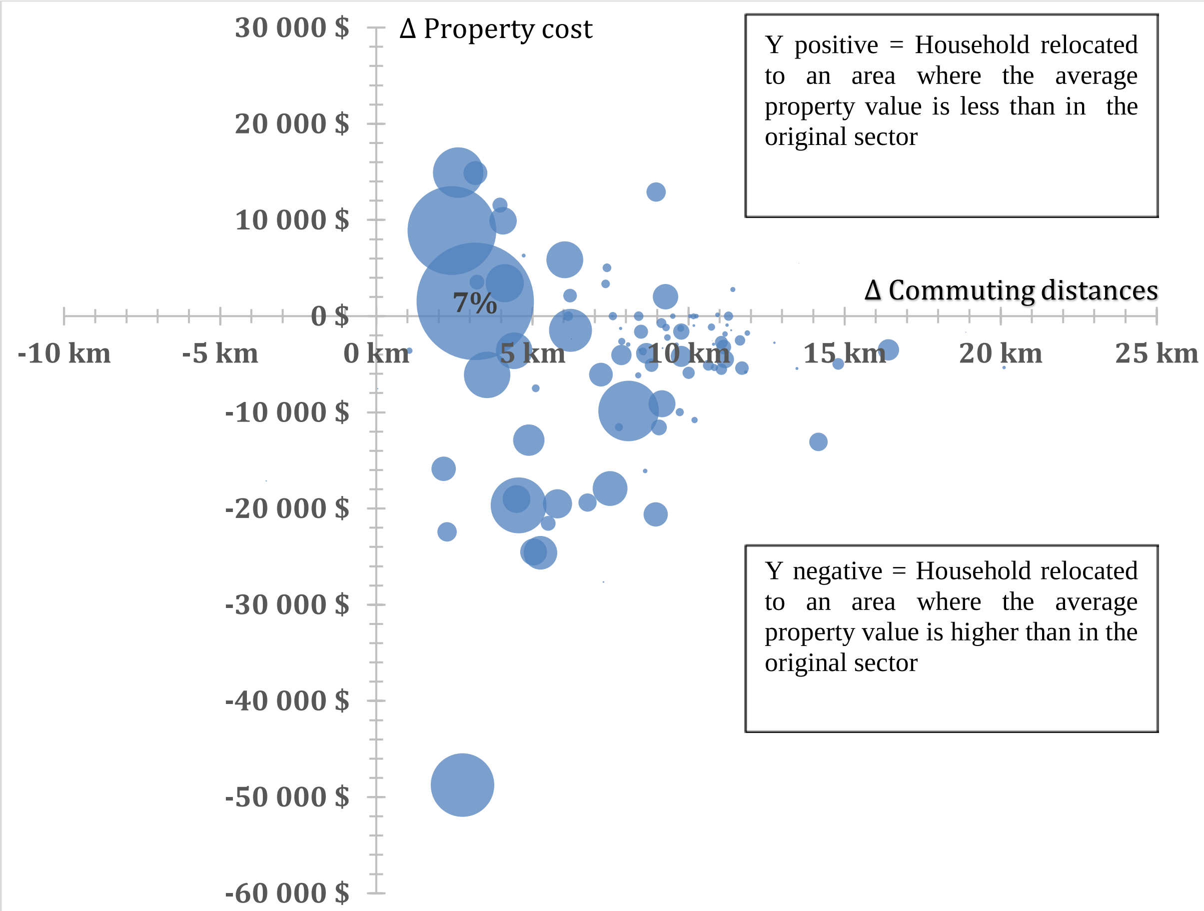

Figure 6: Proportion of households by municipal sector, according to the average commuting distance difference and the housing unit cost between the baseline scenario and the S3

Figure 6 shows that all households reduced their average commuting distance. The relocation happened between sectors with different average property values. More than 70 % of households were relocated to areas where the average property value is higher than the value of their original sector. This economic constraint should be taken into account in the optimization model to obtain results that are compatible with the property cost so that workers will be relocated to a house they can afford.

IMPROVING THE MODEL: SIMILARITY INDEX

The constraints used in this study are household size, house-type preference and tenure type. Other parameters, such as property cost, commuting time and neighborhood preferences are not included in the model. To take all these parameters into account, a similarity index between sectors could be developed. This index would add additional variables to the model, thus adding constraints to the optimization and further decrease the savings in total commuting distances. A similarity index measuring the degree of correspondence between sectors could be developed using various measures, such as:

Sector demographics

a. *Average age of households*

b. *Average household size*

c. *Flexibility of work location of workers in household (regular vs irregular place of work)*

d. *Household structure*

e. *Average household income*

f. *% of households speaking each language…*

g. *% of households belonging to a visible minority or aboriginal status*

Housing characteristics

a. *House-type*

b. *Tenure type*

c. *Property cost*

Neighborhood accessibility

a. *Public transportation*

i. *Average distance to subway stations*

ii. *Bus stops density and frequency*

iii. *Average time to leave the sector*

- *Access time to subway stations*
- *Waiting time at subway stations*

b. *Road network (motorways, express roads, etc.)*

i. *Average time to exit the sector by driving*

A coefficient will be assigned to each component depending on its influence on the choice of place of residence. Households will therefore be relocated to areas with similar characteristics to their area of residence.

CONCLUSION

The Greater Montreal Area (GMA) is suffering from acute congestion problems. This paper evaluated the optimization of home-work distance scenarios. The study was conducted using two sources of data, the 2008 OD survey and the 2011 NHS. The process was composed of three theoretical optimizations minimizing the distance separating workers' home locations and their respective workplaces. The optimizations aim to reduce the average daily commuting distance in the GMA by redistributing households into existing housing. The analysis was performed macroscopically. The municipal sector scale was used because of the lack of data on the house-type preference at the individual scale. The commuting distance was calculated as the Euclidian distance between the centroid of the municipal sector of origin and that of destination, which was about 12.9 km on average in the GMA.

The first optimization (S1) which only considered household size as a constraint reduced daily commuting cost by 58 %, to 4 743 577 pers-km, down from 11 308 574 pers-km. The second (S2), which considered house-type preferences, optimized the daily commuting cost to 5 424 141 pers-km. Finally, when considering all the constraints (S3), including tenure type, the daily commuting cost was reduced by over 51 %, to reach 5 718 749 pers-km. A spatial analysis of the results was performed in order to identify the sectors subject to the most significant changes. The center of the Island of Montreal, Longueuil and Laval-Pont-Viau are the areas whose new residents would be the closest to their workplaces.

Contributions

This paper provides two main contributions. First, it introduces a methodology based on three constraints to evaluate the potential of an optimization of a home-work distance scenario. The methodology is described so that anyone can easily implement the optimization by using one's own data. The tools and methods used are listed in this paper.

Secondly, the results show that Montreal workers are poorly distributed over the territory of the GMA. Indeed, total commuting distances could be reduced by over 51 %.

Limitations

There are limitations to this study. First, the commuting distance used for the optimization is a straight line distance, because the actual path taken by each worker is not known; the 2008 OD survey does not contain such information. Thus, this methodology does not take into consideration the existing road network, and commuting time should be considered instead (White as quoted by Kim 1993).

Secondly, the study considers the commuting distance as the distance between the centroids of the municipal sectors of workplace and residence. A disaggregated approach would have provided more accurate results. The lack of data at the individual level prevented a more disaggregated analysis.

Finally, only the household size, house-type preference and tenure type were used as constraints for the optimizations. To improve the model, a similarity index between municipal sectors could be developed. Potential components of this index were introduced in this paper.

Perspectives

The study could be updated using the commuting times reported in the 2013 OD survey instead of commuting distances. Home-school distances could also be integrated in the model as they are conditioned by the location of the household. In addition, the transit-commuters could be taken into account in the model by considering their home-work distance using the transit network.

Ultimately, it would be interesting to develop a tool that assists workers in choosing their place of residence. This tool would help them find a house that optimizes their commute depending on their mode of transportation and that would also meet their personal preferences (house-type, neighborhood, etc.).

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