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Estimating latent cycling and walking trips in Montreal

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INTRODUCTION

Many cities are looking for strategies to increase the modal share of walking and cycling and thereby reduce the negative impacts of car trips. An increase in the use of active transportation modes can have several positive impacts on air quality and public health. Often, transport authorities are wondering what investment would be needed to increase the modal share of a mode of X% or what would be the increase in the modal share if an infrastructure Y was built. However, they are rarely provided with estimates of what is the maximum market for these modes under the assumption of constant travel demand. One can assume that a mode which share is near the estimated maximum has less potential for improvement than others. The estimation of the potential market of modes could help decision-makers to prioritize types of project, especially if the focus is on walking and cycling. In transport plans, the proposed orientations and projects often come with modal share targets. Nevertheless, fixing these targets in the plans could be a difficult exercise because several other aspects as urban design could have an influence on modal share. Propose a target based on the level of potential achievement could be a good alternative to the actual indicator and could at least assess what would be plausible.

In the Montreal area, despite projects and strategies promoting active modes and the addition of dedicated infrastructure, modal shares of walking (10.1%) and cycling (1.6%) are relatively small compared to the car (54.3%). In this context, it seems relevant to assess the potential of cycling and walking. This paper proposes a methodology to estimate the latent walking and cycling trips in an urban area using large scale Origin-Destination (OD) data. It builds on previous research on latent cycling and walking trips and improves the process by accounting for the distance overlapping zone for walking and cycling trips to obtain a pooled estimation of active transportation latent trips. Estimation of latent trips with OD data involves the estimation of threshold distances for walking and cycling and the development of several criteria to identify trips that could potentially be made by walking or cycling.

This paper first proposes some background elements regarding the estimation of latent walking and cycling trips. It also discusses factors and criteria to account for when estimating potential for active transportation modes. The methodology is then detailed. We first use declared walking and cycling trips to estimate threshold distances according to gender and age group. Then, we apply a sequential process to estimate the latent trips for walking and cycling. Estimation results of latent trips and the impact of these on modal share are afterward presented. A conclusion, some limitations and perspectives follow.

BACKGROUND

The study of the potential of active modes requires to know and understand the factors that can encourage or limit the use of these modes for a trip. Usually, methods to estimate the walking and cycling potential are based on some exclusion criteria applied on motorized trips based on these factors. In the literature, several authors discuss elements that can influence the demand of active trips. Goldsmith (1992) makes a good literature review on the subject. It highlights several factors that influence the cycling and walking demand. Factors mentioned include trip distance, traffic safety, physical condition of individuals, convenience, weather conditions and topography. Certain of factors mentioned are specific to cycling such as presence of cycle facilities, access and linkage to these and traffic conditions. Also, some factors mentioned are specific to walking such as presence of sidewalks, traffic signals, pedestrian crossings, street lighting and presence of attractive places to walk. Porter et al. (1999) also propose factors influencing the active trips demand. These factors include weather, population characteristics, supporting policies, land use, link and network characteristics and characteristics of other modes. Other factors including the safety perception during the trip for walking (Handy and Xing, 2011), the fear of getting his bike stolen (Nettle et al., 2012), the household bike ownership and the presence of a bikesharing system nearby (Guo et al., 2017) are also highlighted in the literature. Chan and Ryan (2009) propose a literature review of factors influencing active trips. The temperature as well as the weather events (precipitation, snow, wind) are among the factors listed. Piatkowski et al. (2014) identified three types of barriers to increase commuter cycling: safety and infrastructure, convenience and climate, and cost and concerns.

The impact of weather on the use of active modes, especially for cycling, is studied by several authors. Temperature, humidity, rain or snow precipitation and wind are regularly mentioned to explain variations in cycling trips. Miranda-Moreno and Nosal (2011) conclude that the rise in temperature has a positive impact while the humidity has a negative impact on the bike ridership. In addition, the combination of these two factors leads to a more significant negative impact. Ahmed et al. (2012) show that about 50% of cycling trips variation would be explained by the weather conditions, making it one of the most important factors. The main explanatory factors are the following: low and heavy rain, strong winds, sunny hours and apparent temperature. Brandenburg et al. (2007) mentioned that cycling is usually used during fine weather. They define this state as a sunny period with a temperature of at least 5 Celsius with no precipitation. Richardson (2000) also shows that very cold or very hot weather and rainfall reduce the probability to cycle. In summary, extreme weather (very hot or very cold temperature, strong winds, precipitation) usually have a negative effect on the use of active modes.

Some authors also show that trip types such as recreational and irregular trips are more impacted by weather factors. Meng et al. (2016) also demonstrated that the irregular trips are under-represented in difficult weather conditions. Other authors also mention that the season and the month also have an impact on the cyclist volumes (Tin Tin et al. (2012), Ahmed et al. (2012), Miranda-Moreno and Nosal (2011)). However, these variables habitually correspond to a proxy for the weather factors previously mentioned. The weather is an external factor that we can not change. However, it is always possible to adapt certain infrastructure in order to minimize some of the disadvantages of weather (Thomas et al. (2009), Brandenburg et al. (2007), Richardson (2000))

Several other factors can influence the number of cycling and walking trips made. Topography, slopes and elevation are important explanatory factors for active trips because they influence the energy needed to make a trip. Heinen et al. (2010) and Parkin (2008) mention that topography and slope undergone during a trip by walking or cycling influences the amount of effort needed to make this trip and is therefore a hindrance to the use of these modes. They also conclude that age, gender and activity purpose can have an impact on the number of active trips observed. In addition to influencing the mode choice, these can also influence the route choice to get to the destination, and thus increase the trip distance. Land use and infrastructure dedicated to active modes are also an important factor.

Shoner and Levinson (2013) show that build environment such as land use and cycling infrastructure have an impact on people mode choice and route choice. Land use favoring compact development can also reduce trip distance and thus increase the potential of active modes (Goldsmith, 1992). Marshall and Garrick (2010) mention that dispersed land uses, bad network connectivity and a lack of cycling infrastructure can be negative factors for cycling use. They also mention that the increase in intersection density and connectivity is habitually associated with more walking and biking trips. In addition to the existence of infrastructure, it is also necessary to ensure that they are in good condition for safe use. Mateo-Babiano et al. (2016) show that bicycle lanes have a positive impact on cycling demand. According to Guo et al. (2017), household bike ownership and the presence of a bikesharing system nearby have also an impact on cycling travel demand.

Another common criterion that has an impact on walking and cycling trips in the literature is the trip distance. Krizek et al. (2009) and Aoun et al. (2015) suggest that one important criterion for estimating trips that could be transferred to walking or cycling is the maximum distance than people can walk or cycle. Several authors propose some minimal and maximal distances for walking and cycling trips. Most studies propose a maximum distance, but only a few propose a minimum one. The estimation of latent trips for active transportation modes are often based on the concept of short trips. However, the definition of short trips could be different depending on the city, the trip behaviour of users, age and gender. For walking distance, many set a fixed maximum distance of 1 km or 1 mile (Morency et al. (2007), Monzon and Vega (2006), Aoun et al. (2015), Ahrens et al. (2013)). Some authors propose a range of distance between 400 m and 600 m for walking trips (Iacono et al. (2008), Olszewski and Wibowo. (2005)) while Krizek et al. (2009) propose a fixed distance of 800 m.

However, this method sets a fixed threshold distance for the whole population despite the fact that children and elderly could have shorter threshold distances. Therefore, other propose threshold distances which vary according to age (Panter et al. (2008), Kemperman and Timmermans (2009), Poliquin (2012), Godefroy et al. (2012)). Pont et al. (2009) have shown that the walking threshold distances to go to school for children should be 1,421 m at 10 years, 1,627 m at 11 years and 3,046 m at 14 years. Nelson et al. (2008) conclude that the maximum distance for teenagers to go to school walking or cycling is less than 4 km. Van Dyck et al. (*2010*) studied threshold distances of children in Belgium and conclude that it should be 1.5 km for children and between 2.0 km and 2.4 km for teenagers. Chillon and al. (*2015*) studied the distance between home and school. Their results show that distance should be 1.4 km at 10 years, 1.6 km at 11 years and 3.0 km at 14 years.

Several threshold distances for cycling trips are also proposed. Distances between 5 km and 8 km are often used as threshold distance (Aoun et al. (2015), Ahrens et al. (2013)). Others rather propose a maximum cycling distance of 2500 m (Pooley (2011)). Threshold distance may also vary depending on trip purpose (Krizek et al. (2009), Iacono et al. (2008)). It is not uncommon to see leisure trips more than 10 km long while distance is usually shorter for other purposes. Krizek et al. (2009) also reveals that there is usually a decline of cycling trips after 4 km. Results for walking and cycling threshold distances and their estimation methods vary from one study to another. Therefore, results between studies and cities are quite difficult to compare without the use of similar criteria. In addition, other criteria use for estimating latent trips are rarely explained.

Several studies provide methodologies to estimate the potential of cycling or walking. Pospischil and Mailer (*2014)* analyzed the increase in cycling modal share (from 13% to 23%) between 2002 and 2011 in Innsbruck. They used a trip survey to estimate trips that can be made by cycling assuming that all trips between 1 and 5 km long could be transferred. Results show that 43% of all trips are between these threshold distances and 35% of them were initially car trips. They conclude that despite the significant increase in modal share, there is still potential to increase it further.

A study in London estimates the cycling potential (Transport for London (2010)). Results show that 35% of the motorized trips could be made by cycling. Criteria use for these estimations include threshold distance of 1 km for walking and 8 km for cycling and an age between 5 and 64 years. Monzon and Vega (2006) present a methodology to estimate trips transferable to public transit and sustainable modes. Results show the 9% of car trips could be transferred to walking, 11.5% to cycling and 13.6% to public transit. Criteria use for these estimations include threshold distance of 1.5 km for walking and 3.5 km for cycling and age between 18 and 50 years. Mckibbin (*2011*) use a stated preference survey to estimate the potential of modal shift to reduce emissions in Northern Ireland. Results show than fewer than 10% of people would choose cycling over car and 33% would choose walking instead of the car.

The process we propose in this paper is a follow-up to previous work by Morency et al. (2014), Morency et al. (2009), Morency et al. (2007) and Morency et al. (2011) on latent walking trips and by Godefroy and Morency (2012) on latent cycling trips. Morency et al. (*2007*) and Morency et al. (*2009*) have developed first a methodology to estimate the walking potential and the steps in reserve in the Montreal area. Subsequently, they changed distance in number of steps according to age and gender. Poliquin (*2012*) has improved the proposed method by adding the concept of threshold distance according to age group and gender. Result show than 7.7% of motorized trips in 2008 could be transferred to walking. Godefroy et al. (2012) have applied the methodology developed for latent walking trips by adapting it for cycling on the island of Montreal. They estimate threshold distance for cycling according to age group and gender. When accounting for trip chain structure, they estimate that 18.2% of car trips could be made by bike.

Most of the methodologies estimate the potential of cycling or walking independently. It is therefore rare to have the global potential of active transportation modes. Indeed, a part of the potential walk trips could also be done by cycling according to several criteria and vice-versa. Some authors include a minimum cycling distance in their methodology to ensure not to have overlapping zones between the latent walking and cycling trips. However, in order to simplify the process, the minimum distance for a cycling trip is often set as the maximum distance for a walking trip (Pospischila and Mailera, (2014). Although this assumption simplifies the estimations, it supposes that walking and cycling distances are mutually exclusive, which is not necessarily the case.

Among the methods for estimating the potential of walking and cycling trips, many of the factors mentioned in the literature review are little or not included in the methodologies, which is based primarily on travel distances. Temperature, weather conditions, elevations encountered during the trip, land use, number and state of infrastructure as well as the personal attitude on active modes are all factors that can limit the transfer to active modes. Although these factors are not taken into account in these methodologies, they partly explain why the estimated potential is not yet reached and can give guidance on the strategies to be proposed in order to reach it. These methodologies are therefore more aimed at determining the upper limit of the potential for a constant demand.

GENERAL METHODOLOGY

The Montreal Area regularly conducts large-scale OD travel surveys. In 2013, the 10th OD survey was conducted in the region with a 4% sampling rate. Some 79,000 households participated and spatial-temporal information as well as details regarding transportation modes were collected for some 400,000 trips. Bike ownership is not available for households and people. These data are used to construct a detailed analysis of the typical daily travels in the region. This study focuses on the Greater Montreal Area (GMA) which has a population of some 4.3 million people and 1.8 million households. In 2013, the population has made some 9.1 million trips during a typical weekday. Each observed trip in the survey is weighted to represent the trips of the GMA entire population. Weighting factors are based on sociodemographic and spatial attributes of households and people.

The overall methodology we propose consists of examining individual trips and sequentially removing those not respecting certain criteria. The proposed methodology involves several steps:

1) Extraction of individual trips from OD survey;

2) Estimation of threshold distances by age and gender for walking and cycling;

3) Application of several criteria based on trip distance, trip purpose and trip chain to exclude trips that could not be transferred to walking or cycling.

4) Overlapping process to consider trips that can be done by walking and cycling according to estimated threshold distances for both modes.

As mentioned previously, the main criteria used to exclude trips are based on trip distance, trip purpose and trip chain. The objective of this methodology is to establish the upper limit of the potential of active modes under the assumption of constant travel demand, while being aware that this potential will be difficult to reach. Some factors previously mentioned in the literature review are not included in the methodology. However, these factors partly explain why this potential is not yet reached and can give guidance on the most appropriate strategies to reach it.

Extraction of trips

For estimating latent walking and cycling trips, all motorized trips of the OD survey are extracted. There are about 8.26 million trips which could, initially, be transferred to walking or cycling. In addition to these motorized trips, there are also 973,303 walking trips and 153,001 cycling trips, which correspond respectively to a modal share of 10.1% and 1.6%. These trips are not included in the estimation process and will remain walking or cycling trips after calculations. Moreover, the trip chains including these motorized trips are also extracted to be considered in various exclusion criteria. A trip chain is defined as a sequence of trips made by a person starting and ending at the home location. The complete definition of trip chains used in this study was developed by Valiquette and Morency (2010).

Threshold distances

The concept of threshold distance is important to estimate latent trips for walking and cycling. It corresponds to the maximum distances for which a trip can possibly be transferred to another mode. The methodology used to estimate threshold distances for walking and cycling is based on the work of Godefroy and Morency (2012) and Poliquin (2012). Estimating the latent trips for active modes requires to calculate threshold distances for walking and cycling independently. The maximum threshold distance corresponds to 80th percentile of the walking trip distribution of the OD survey. Moreover, these distances are estimated for several segments of the population because threshold distance may be different according to age and gender. Population segments are therefore based primarily on physical capabilities of people, evolving quickly for children, and on similarity of the trip behavior. Age groups are therefore smaller for children under 18 years and larger for adults. Objective of threshold distances is to consider only trips that are feasible with active modes by most of the population and eliminate too long trips. The use of the 80th percentile is an arbitrary choice made in Godefroy and Morency (2012) and Poliquin (2012). However, a sensitivity analysis of this parameter is presented further to assess its impact. Network distances have been used to consider barriers such as highways, railways, bridges and rivers. Table 1 shows the maximum threshold distances for walking according to age groups and genders.

TABLE 1 Maximum threshold distances for walking trips by age and gender.

	Network distance(m) 80th percentile	
	Men	Women
5-6 y.o.	761	835
7-8 y.o.	828	829
9-10 y.o.	854	925
11-12 y.o.	1,013	1,045
13-14 y.o.	1,579	1,465
15-17 y.o.	1,611	1,480
18-24 y.o.	1,664	1,564
25-40 y.o.	1,524	1,369
41-64 y.o.	1,558	1,426
65 -74 y.o.	1,419	1,336
75-89 y.o.	1,178	1,019

Threshold distances increase with age until 24 years old for both men and women. The average threshold distance is higher for men (1426 m) than women (1306 m). However, for children under 13 years old, the average threshold distance is lower for men (864 m) compared to women (908 m).

For cycling trips, like walking trips, there is no minimum threshold distance. The maximum threshold distance for cycling is determined as for walking and corresponds to the 80th percentile of cycling trip distribution. The age group are not the same for cycling and walking due to sampling size. Larger groups are used for cycling in order to have sufficient observations and less variability in the distribution. Moreover, these groups show similar trip behaviors for cycling. Table 2 shows the maximum threshold distances for cycling according to age groups and gender.

TABLE 2 Maximum threshold distances for cycling trips by age and gender.

	Network distance (m) 80^{th} percentile	
	Men	Women
5-12 y.o.	1,622	1,790
13-17 y.o.	4,220	4,887
18-40 y.o.	6,210	6,302
41-64 y.o.	7,190	5,511
65-74 y.o.	5,189	3,945

The average maximum threshold distance is higher for men (5734 m) than women (5077 m). However, for children under 18 years old, the average threshold distance is lower for men (2610 m) compared to women (2981 m).

Latent trip estimation process for walking and cycling

The methodology for estimating latent trips for walking and cycling consists in applying a series of conditions to motorized trips. The result is a set of trips that could be transferred to walking or cycling. Trips that do not meet one condition of the walking process can after pass through the cycling process. Criteria proposed here are mainly based on previous work that has been discussed in Godefroy and Morency (2012) and in Poliquin (2012). However, the criterion for the overlapping area between walking and cycling latent trips is an addition to the methodology already developed and will be explained further. Also, network distances are used instead of Euclidean distances. The following criteria are applied on all motorized trips:

Walking criteria

All the following criteria must be met for a trip to be transferable to walking:

1. Age of the person should be between 4 and 90 years.
2. Trip distance should be smaller than the threshold distance for walking.
3. Criteria based on trip chains:
   A) Each trip distance in the chain should be smaller than the threshold distance for walking.
   B) Total distance of the trip chain should be smaller than four times the threshold distance.
4. Overlapping criteria: if a trip also meets the cycling criteria, then apply the overlapping process.

Cycling criteria

For a trip be transferable to cycling, all following criteria must be met:

1. Age of the person should be between 4 and 75 years.
2. Trip distance should be smaller than the threshold distance for cycling.
3. Criteria based on trip chains:
   A) Purposes for all trips of the chain should not be for shopping or picking up someone.
   B) Trip chain must have a return home trip
   C) Each trip distance in the chain should be smaller than the threshold distance for cycling.
   D) Total distance of the trip chain should be smaller than four times the threshold distance.
4. Overlapping criteria: if a trip also meets the walking criteria, then apply the overlapping process.

Criterion (3A) for cycling, excluding all trip chains involving a shopping activity is probably too restrictive. Some types of shopping trips can be done by cycling easily. However, others simply cannot be done by cycling because they involve carrying a heavy load. We estimate that 6.9% of cycling trips in 2013 were made for shopping. Without more detailed segmentation of the shopping purpose in the OD survey, it was assumed that all the shopping trips would be excluded. However, we know that this hypothesis is not perfectly true. In a similar way, we also know that some shopping trips cannot be done by walking. However, it was assumed that all the shopping trips could be done by walking if they met other criteria due to the proximity of the trips. This criterion also assumes that it is impossible to pick up someone by bike. Although it is difficult to be more than one on the same bike unless the second person is a child, it is possible to drive a person who has his own bike. In 2013, 1.2% of cycling trips were made to pick up someone. To simplify the process, it was assumed that the pick up trips would be excluded from the cycling potential. Criteria 2B for walking and 3D for cycling, that limit the total distance of the chain to four times the threshold distance, were set considering observed daily travel behavior.

Overlapping process

The overlapping process is based on a concept of overlapping area between the distance distribution of walking and cycling trips. This process allows to allocate trips that meet all criteria for both modes to walking or cycling latent trips. In the literature, latent trips are usually estimated in a non-mutually exclusive way. A trip can be part of the latent trips for walking and cycling. The combined potential of these modes cannot be estimated as it does not correspond to the some of their own potential. In order to estimate the combined potential of active modes, a new approach is proposed here.

Trip distance distribution for walking and cycling are lognormal for each age group and gender. Trips that meet both walking and cycling criteria for latent trips, will be divided according to the relative share of walking and cycling for a specific distance. The number of walking and cycling trips for a specific distance are estimated from the modelled distributions. Figure 1 is illustrating the process for a trip i.

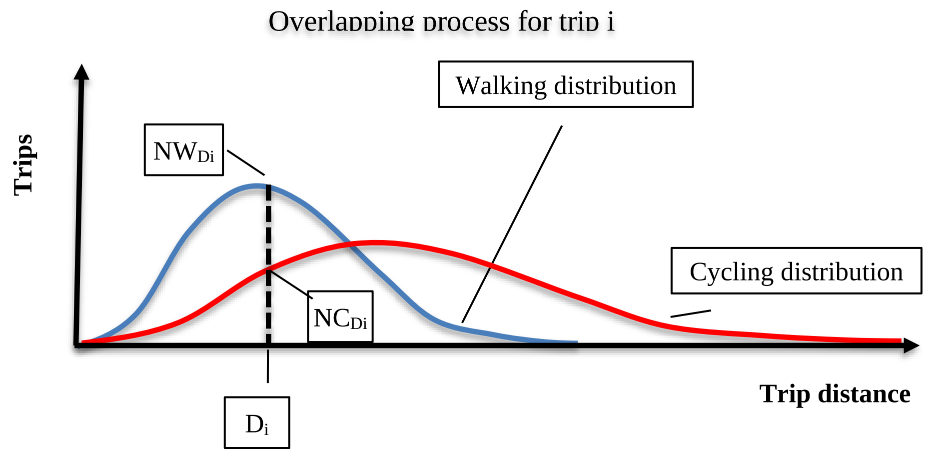

FIGURE 1 Overlapping distance area for latent walking and cycling trips

In Figure 1, D_i is the network distance of trip i, NW_{Di} and NC_{Di} are respectively the modelled number of walking and cycling trips for a specific distance (D_i). It is worth mentioning that since we are using observed trips from a travel survey, each trip has a weighing factors that allows to reconstruct the reference population of trips (weights are around 25 since the sampling rate is around 4%). Hence it is easy to split this weight during the overlapping process to estimate latent trips for both active modes. Proportion of each trip weight is therefore transferred to latent walking trips and latent cycling trips. These proportions for a trip i are estimated as follows.

- If trip i meets both walking and cycling criteria, then:
  - $p_{Walking_i} = \frac{NW_{Di}}{NW_{Di}+NC_{Di}}$;
  - $p_{cycling_i} = \frac{NC_{Di}}{NW_{Di}+NC_{Di}}$.

Where p is the proportion of the weighting factor of trip i that is transferred to walking and cycling.

Trips that meet criteria for walking but not for cycling are fully transferred to walking latent trips. Conversely, trips that meet criteria for cycling but not for walking are fully transferred to cycling latent trips. All motorized trips follow the decision-making process shown in Figure 2.

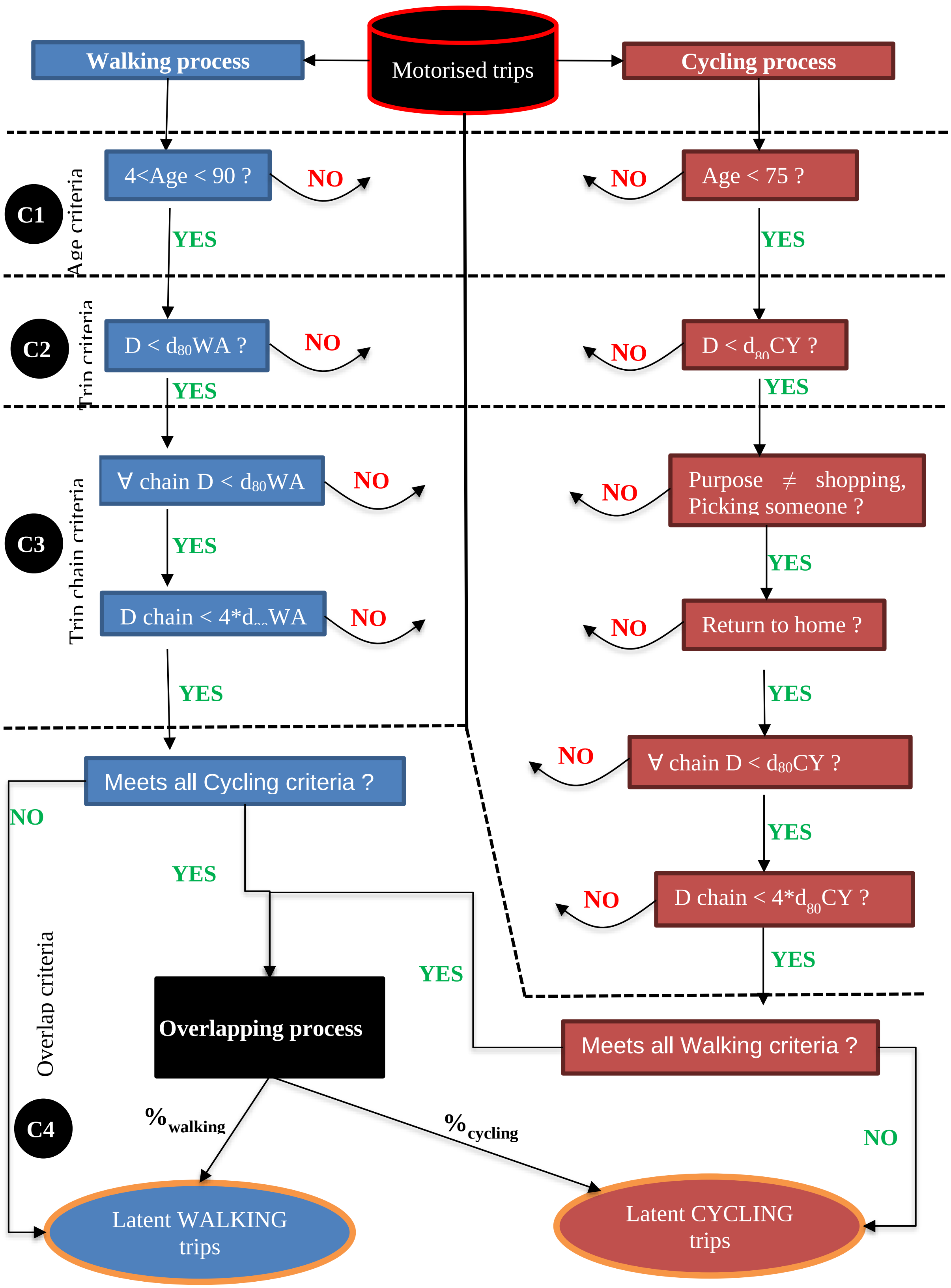

FIGURE 2 Estimation procedure for latent walking and cycling trips (WA: Walking, CY: Cycling)

Results of this decision-making process are the amount of latent walking and cycling trips. Trips that meets all criteria for walking and cycling must be split during the overlapping process.

RESULTS

The proposed methodology allows to evaluate the total number of walking and cycling latent trips. Still having, after the process, the observed characteristics of people and trips, it is also possible to know which modes or which activity purpose most contribute in latent trips. Finally, it is also possible to assess the impact of latent trips, if they were actually made, on several mobility indicators such as modal shares.

In addition to the overall results, Figure 3 presents in detail the impact of each criterion applied in the methodology by specifying the number and the percentage of motorized trips discarded at each step. A total of 8.26 million motorized trips go through the walking and cycling process. Both processes are independent. However, it is necessary to identify trips that meet all criteria of walking and cycling latent trips.

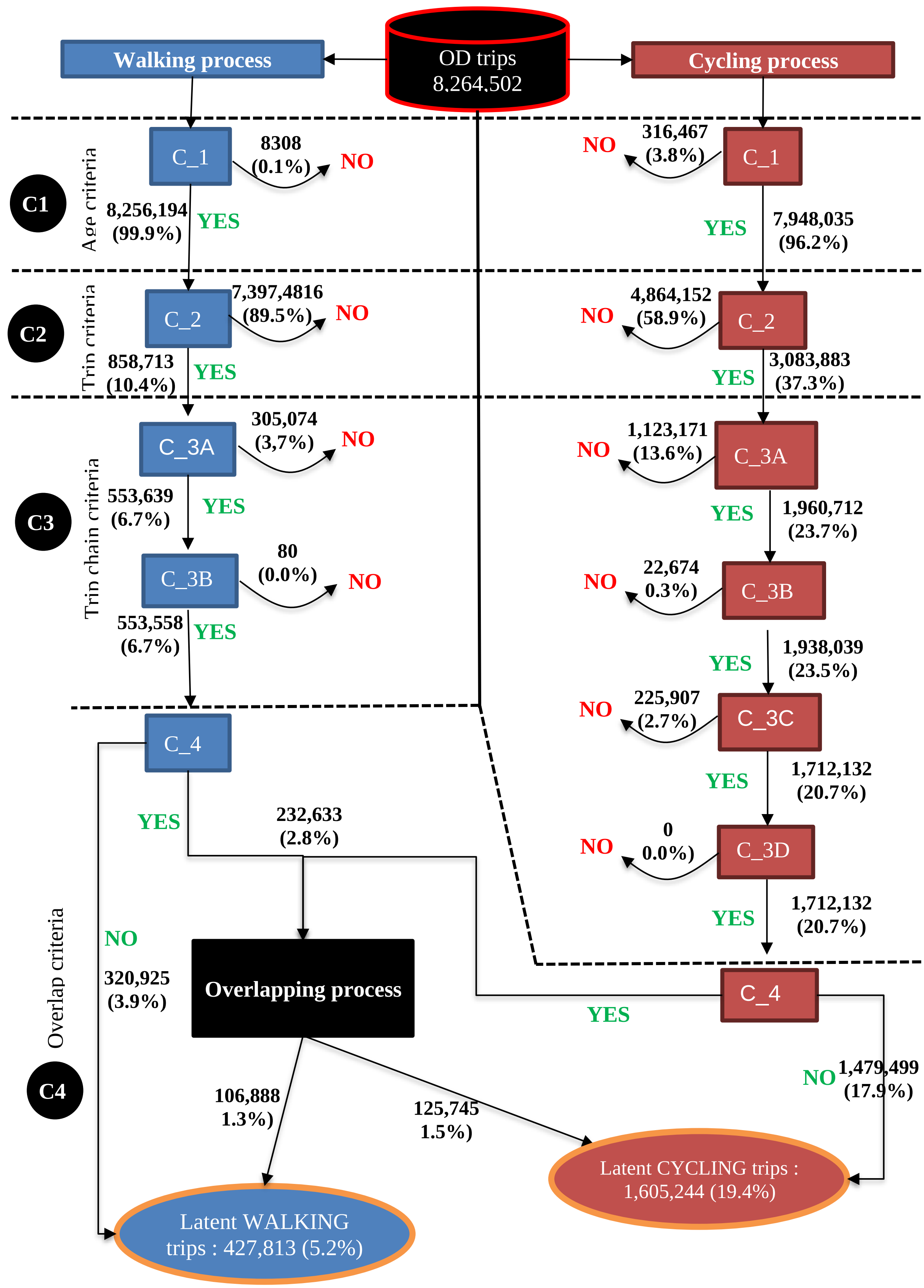

FIGURE 3 Results for each step of the latent trip process.

Among all criteria, criterion C2, based on threshold distance, is the most discriminant criteria during the estimation process. Trips excluded at this stage for the walking and cycling process are respectively 89.5% and 58.9% of motorized trips. Among all motorized trips, 6.7% of them meet the criteria for latent walking trips and 20.7% of them meet those for latent cycling trips. 2.8% of motorized trips meet all the criteria for latent walking and cycling trips. These trips must be split with the overlapping process. From those, 45.9% (106,888 trips) are transferred to walking and 54.1% (125,745 trips) to cycling. Final results show that among all motorized trips, 24.6% are transferable to walking or cycling. About 5.2% of the trips, or 427,813 trips, can be considered as latent walking trips. For cycling, the number of latent trips is 1,605,244, which is 19.4% of motorized trips.

All these latent trips are initially observed motorized trips and are not distributed equally among all modes. Table 3 shows the distribution of latent walking and cycling trips according to their initial mode. The largest share of transferable walking and cycling trips comes from car driver trips. More than 1.16 million car driver trips, which is 57.1% of all latent trips, could be removed from the road network if all latent trips materialize. Table 3 also shows the percentage of latent trips per mode. One of the highest percentages comes from school bus trips (30.0%). Most of these trips are made for study purpose and usually involve only two trips. We also observe that the percentage of trips transferable to walking per mode are higher for car driver and car passenger trips, which are 6.1% and 6.4% respectively, compared to other motorized modes. There is thus a larger proportion of short trips for these modes. This can also be explained by a large proportion of school trips made as car passengers. These automatically involve a car driver trip in addition to the car passenger trip and increase the percentage of latent walk trips.

TABLE 3 Trips and the percentage of trips by mode which can be transferred to walking and cycling.

	Latent trips			Percentage of trips		
Mode	**Walking**	**Cycling**	**Total**	**Walking**	**Cycling**	**Total**
Car driver	313,830	846,182	1,160,013	6.1%	16.4%	22.5%
Car passenger	75,495	266,026	341,520	6.4%	22.6%	29.0%
Public transit	25,500	367,483	392,983	1.9%	28.0%	30.0%
School bus	6,466	94,682	101,148	1.9%	27.2%	29.0%
Other motorized	6,522	30,871	37,393	2.4%	11.2%	13.6%

These results assume that travel demand remains constant. We suppose that the potential decrease of car trips will not affect traffic conditions and the distribution of other motorized trips. Table 4 shows the percentage of transferable trips by activity purpose. For the walking latent trips, the highest percentage is for shopping purpose. 9.8% of shopping trips could be transferred to walking. This can be explained by the fact that shopping trips are excluded from the latent cycling process and therefore, 100% of the shopping trips who meet all criteria for latent walking trips are transferred to this mode. 21.2% of work trips could be transferred to active modes. These trips are usually more complex and longer than other trips. The highest percentage of transferable trips is for school activity. 3.5% of the trips could be transferred to walking and 28.5% to cycling. Leisure trips also have a high percentage of latent trips with 30.1%. These trips are usually less constrained in time compared to work or school trips and therefore could be transferred more easily.

TABLE 4 Percentage of latent trips, which can be transferred to walking and cycling, by purpose.

	Percentage of latent trips		
Purpose	**Walking**	**Cycling**	**Total**
Work	2.1%	19.1%	21.2%
School	3.5%	28.5%	32.0%

Return home	5.7%	22.0%	27.7%
Leisure	4.7%	25.5%	30.1%
Shopping	9.8%	0.0%	9.8%
Other	6.9%	14.5%	21.3%

Table 5 shows the modal share of trips before and after the addition of latent walking and cycling trips. Addition of these trips increases modal share of active modes while those of all motorized mode consequently decrease. Indeed, the modal share of walking increases from 10.1% to 14.7% (+ 4.6%) while the one of cycling increases from 1.6% to 18.7% (+ 17.1%). Active modes have a modal share of 33.4% after the addition of latent trips. This modal share is higher than the combination of car passengers, public transit, school bus and other motorized modes. The largest decrease concerns the car driver modal share, which decreases from 54.9% to 42.5% (- 12.4%).

TABLE 5 Modal shares before and after the addition of latent walking and cycling trips.

	Modal shares	
Mode	**Observe in Household survey**	**Including latent trips**
Car driver	54.9%	42.5%
Car passenger	12.5%	8.9%
Public transit	14.0%	9.8%
School bus	3.7%	2.6%
Other motorized	2.9%	2.5%
Walking	10.1%	14.7%
Cycling	1.6%	18.7%

Figure 4 shows the impact of the addition of latent trips on the number of walking and cycling trips per person according to age group and gender. Global trip rates are increasing from 0.23 to 0.33 walking trips per person and from 0.04 to 0.41 cycling trips per person. There is a significant increase in walking trip rates for all age group except for those between 10 and 19 years where the increase is much smaller. For the cycling trip rate, there is also an important increase for all age groups except for people older than 75 years where there were no latent cycling trips. Figure 4 also shows the percentage of latent trips according to age group and gender. The percentage of transferable trips for men and women are quite similar (22.2% for men and 21.1% for women). Children from 5 to 9 years old have the highest proportion of transferable trips with 29.2% for men and 29.3% for women. Elderly people (over 75 years old) have the lowest proportion of transferable trips namely because cycling is not considered.

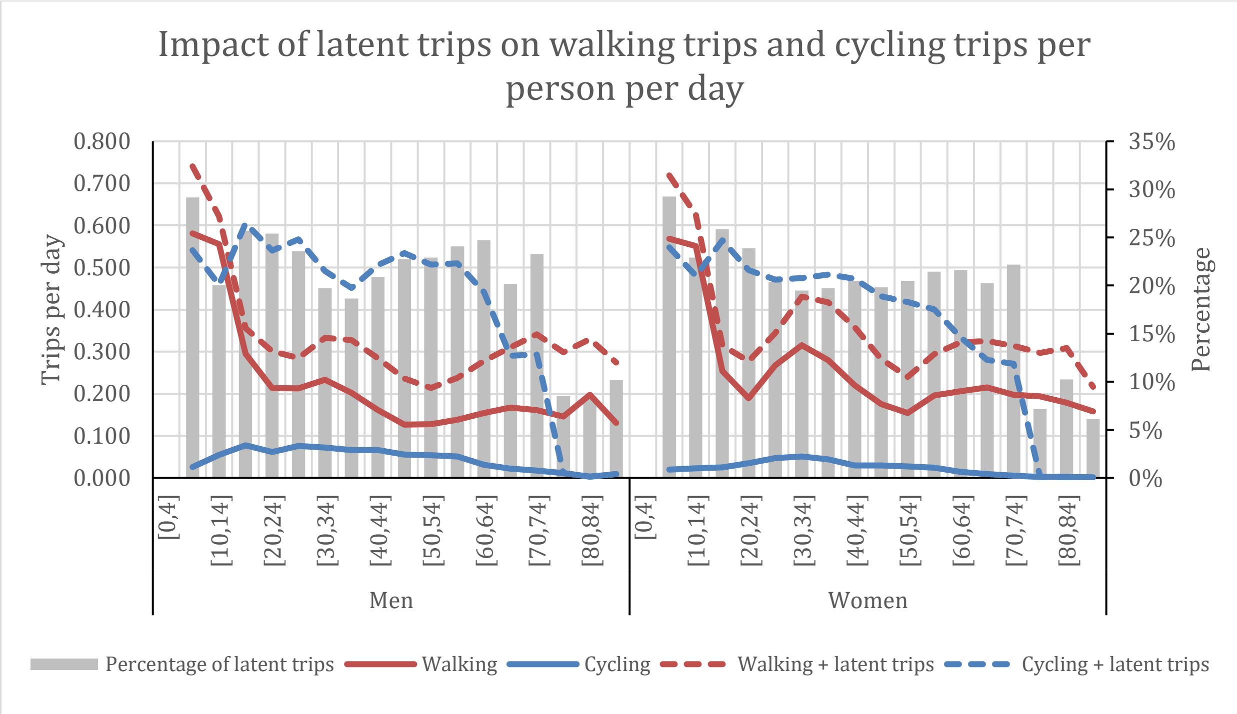

FIGURE 4 Walking and cycling trip rates before and after the addition of latent trips and percentage of transferable trips according to age groups and gender.

SENSITIVITY ANALYSIS

Results presented previously depend on assumptions in the methodology. One of those that has a significant impact on obtained latent trips is the distance distribution percentile used as threshold for walking and cycling trips. The objective of the threshold distance is to consider only trips that are feasible by walking or cycling by most of the population. Although other variables such as physical condition or temperature can have an impact on the trips that a person is willing to do with active modes, only age and gender were considered in this study. Trips that are not considered feasible must be withdrawn. In our case, we want to explore the upper limit of the potential of active modes, then the objective is to consider the most possible trips, as long as they are feasible. In order to assess the impact of the choice of threshold distance, results were compiled by changing threshold distance from 10th to 100th percentile of the observed trips distribution. Results are shown on Figure 5.

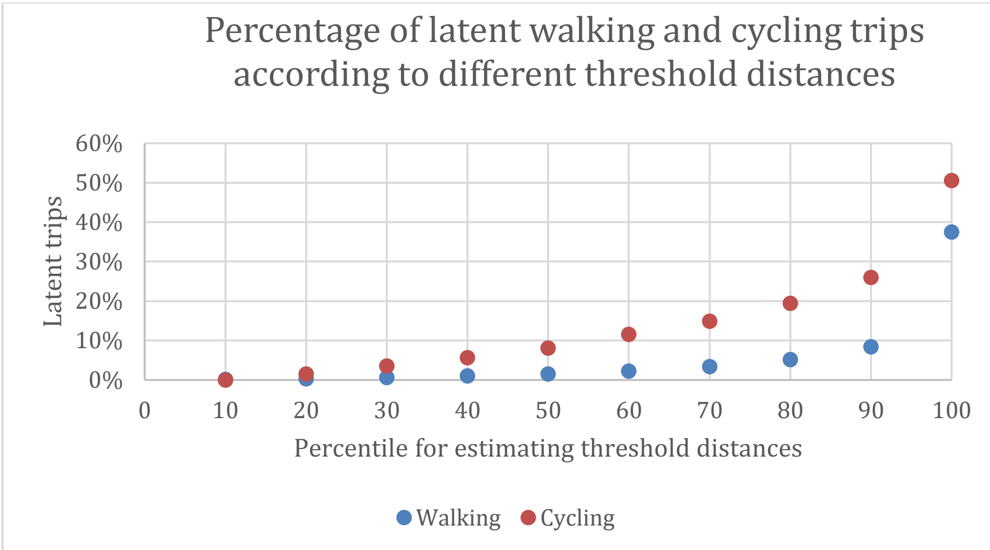

FIGURE 5 Percentage of latent walking and cycling trips according to different threshold distances

Percentage of latent trips increases according to the percentile of the distance distribution used as a threshold. Higher is the threshold, higher are the number of trips that could be latent trips. Although the increase in the percentage of latent trips is gradual, there is a significant gap between the 90th and the 100th percentile. Indeed, percentage of walking and cycling latent trips between the 90th and the 100th increase respectively from 8.4% à 37.5% and from 26.0% à 50.6%. Other differences observed on the graph are much lower than these. Walking and cycling trips between the 90th and the 100th percentile may include none feasible trips that increases too quickly the percentage of latent trips. This also includes the outlier values. It is difficult to choose the optimum percentile value to estimate threshold distances. However, Figure 5 allows to assess the impact of this choice on results.

CONCLUSION

This paper has proposed a standard methodology to estimate the upper bound potential of walking and cycling trips. It also proposed a way to manage trips that could be transferred both to walking and cycling. One of the objectives of this research was also to contribute to the body of knowledge on latent walking and cycling trips. The methodology is mainly based on a sequential process using trips reported in a large-scale OD survey held in 2013 in Montreal. The methodology can be applied to other area with similar data. Criteria are mainly based on trip distance, trip chain and trip purpose. Using threshold distances defined by age group and gender, we estimate the latent walking and cycling trips in the Montreal Area.

Some results can be highlighted:

- 5.2% of motorized trips could be transferred to walking and 19.4% to cycling.
- 57.1% of latent walking and cycling trips were observed car driver trips.
- 2.8% of motorized trips could be transferred to both walking and cycling. These trips are split in the overlapping process where 45.9% of them (1.3% of total trips) are transferred to latent walking trips and 54.1% (1.5% of total trips) to latent cycling trips.
- When we consider latent trips, modal share of walking and cycling increase respectively from 10.1% to 14.7% (+ 4.6%) and from 1.6% to 18.7% (+ 17.1%) while that of car driver decreases from 54.9% to 42.5% (-12.4%).

In practical use, this analysis could help to identify problematic sector where the cycling or the walking potential are far from being achieved. It would hence be interesting to try to understand why there are so many latent trips in these areas. Planning authorities often have targets of increasing modal share of a mode. Nevertheless, these increases do not consider the potential for real increases in these modes. For example, it is probably much more difficult and needs more resources to increase the modal share of a mode by 1% if 90% of the potential of this mode is reached instead of 1% increase if 10% of the potential is reached. In our analysis, we estimated that 8.6% of the cycling potential and 68.7% of the walking one are currently being achieved in the Montreal area. Estimating the potential of a mode could be a good tool for planning authorities to help them to fix targets and priorities.

In addition, results show that there is an overlap area between the trip distance distributions of walking and cycling and therefore, that these modes do not have mutually exclusive distances. In order to estimate the potential to combine active travel, a process must be used to take this area into consideration.

The comparison of the results obtained with those of the previous studies discussed in the background section is complex because of the general context that are different from one city to another. The age of the population, the land occupation, the travel demand, the threshold distances used and other methodological factors influence the results. However, if we compare results with previous studies in the Montreal area. In addition to the overlap process which is a methodological addition in this study, several elements can explain these differences. First, although the trips criteria are similar, there are some methodological differences, the most important being the use of network distances instead of Euclidean distances for trips. The average trip distance has therefore increased. In addition, the methodology used in the studies of Godefroy and Morency (2012) and Poliquin (2012) are based on 2008 data instead of 2013. During this period, the travel demand has evolved. For example, the modal share of walking has decreased from 11.2% to 10.4% and that of cycling increased from 1.4% to 1.7%.

Although the threshold distances depend mainly on age and gender, they also depend on the mobility behaviour as well as the characteristics of the estimation region. It is therefore not recommended to apply threshold distances estimated in this study in another context. However, the methodology for estimating these threshold distances can easily be applied elsewhere.

Limitations and perspectives

There are some limitations and perspectives to the current estimations. With network distance, the methodology could be used to estimate the increase in the walking and cycling potential caused by the addition of new infrastructure such as new cycle path on a bridge where it was previously impossible to go through. Evaluating the increase in the potential of active modes can therefore become an interesting and relatively simple indicator to assess the effectiveness of adding infrastructure.

In addition to distance type, the route grade could also have an important impact on distances that people are willing to walk or cycle. Slope could therefore be considered by weighting the trip distance or by adding new criteria in the estimation process that would limit the increase in altitude for a trip to be transferable to walking or cycling. In addition, estimated network distances are based on a shortest path algorithm. Calculation based on a generalized cost including slope could be tested.

Other criteria based on network characteristics such as availability of cycle way or sidewalk could also be considered. In addition to the analyses presented above, it would also be interesting to study the impact of latent trips on networks (pedestrian, cycle, road and transit). The existing pedestrian and cycle infrastructure may not be sufficient to accommodate all the latent trips.

The criteria used for trip chains may be too restrictive. To be a latent trip, all the trips in the chain must satisfy the latent trip criteria. However, this neglect trip loops inside a trip chain that could be done by walking or cycling. For example, a person who is going to pick up a lunch in the afternoon and then returns to his working activity could be counted as a latent trip. The methodology presented should be adapted to consider the loops inside the trip chains. In addition, alternative modes have emerged in the last few years that may challenge some of the criteria. Indeed, bikesharing and carsharing could make possible a trip inside a chain that would be too long to be done by walking or cycling. According to the current methodology, all the trips of a chain must meet the criteria to be considered as latent trip. These aspects could be implemented in future research. The electric bike is another technology that could challenge the distance criteria by allowing longest distances or minimize limiting factors such as people physical condition, age or temperature. However, the proposed methodology can quickly assess the impact of this new technology on the cycling potential.

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