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A New Method to Measure the Quality and the Diversity of Transit Trip Alternatives

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Abstract. Evaluating public transit supply is far from being a simple task. Complexity increases when one tries to consider all possible alternatives to travel between two points. This research proposes a new method that considers both the quality and the diversity of transit alternatives. The paper highlights that few studies currently focus on the expectations of transit users. We use two surveys from the Montreal region to confirm the importance of a variety of elements on transit perception. Our methodology proposes to identify possible alternatives between origin and destination points and calculate descriptive indicators for each alternative. We then estimate a quality score for each through the use of weighting factors. Alternatives are afterward ranked, based on these scores. The method is tested on ten Origin-Destination pairs located in Montreal. These pairs are represented in a Quality-Diversity quadrant. Different weighting coefficients, putting more or less on some particular indicators, assess the sensitivity of the results. They vary up to 10% in quality when considering some factors three times more important than others. This shows how responsive the method is regarding to the fixed parameters. A conclusion provides some context to the research as well as ideas to improve the method.

Keywords: Public transit, path choice, quality indicator, diversity indicator.

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INTRODUCTION

Increasing the share of public transit is one of the key strategies to move forward with sustainable mobility. In this context, transit needs to improve its attractiveness in order to compete with the private car and improve its market share. But how attractive is transit supply? Measuring the attractiveness of transit may not be such a simple task. There are some indicators that reflect certain aspects of the service such as travel time or number of transfers. However, the user's decision process is complex and typical indicators lack to capture various features that make a transit trip attractive. Besides, with the democratization of smartphones and transit trip calculator applications, it is now easier for people to access transit route information, and to browse through available alternatives to travel between two particular points. Faced with the various options, they may take other features into account to make their final choice.

The main focus of this paper is to expose a new method dealing with the complexity of transit trip alternatives, in order to better evaluate them. An alternative is a particular sequence of routes and transfers. One of our assumptions is that the value of a transit alternatives set increases with the quality of each alternative. It depends on factors such as travel time but many additional ones that will be explained. Another assumption is that the amount of available alternatives gives value to the transit user, meaning that having two alternatives is better than having only one and so on. The proposed assessment method aims to produce indicators for each alternative, leading to their ranking, to finally obtain a score of quality and diversity for the whole set of alternatives.

In this paper, we first have a closer look at relevant transportation modelling concepts. We then focus on the expectations of travelers regarding public transit, by both looking at the Montreal case using survey data, and through the literature on transit quality measures. The general methodology is afterward presented. The proposed method is then tested using ten case studies to observe the effects of different factors. We close the paper with a discussion and identification of research perspectives.

BACKGROUND

Key Elements of Transportation Modelling

Many authors have published reference books that describe the state of the art of transport demand forecasting, like Ortùzar and Willumsen (*1*) or Bates (*2*). They all state that demand forecasting is complex as the demand depends on a variety of variables. When discussing the mode choice step, Ortùzar and Willumsen (*1*) review the different factors influencing that choice. Little is however discussed in discrete mode choice modelling on the impact of having multiple alternatives for a specific trip using a particular mode.

For the trip assignment, the route choice set has first to be developed. Different methods can be used, the easiest being to actually observe which routes are considered by a traveler (via survey or GPS data). We can also use a transit path calculator to obtain the best n routes (*1*). In order to compute the set of routes, a decision must be made between taking only the shortest path between origin and destination or using a multipath method (*3*). There is a variety of researches on path generation methods; Prato presents some of them (*4*). Bovy et al. (*5*) remind that the route choice set should not include routes with too many common segments, nor aberrations that produce irrelevant routes. Many authors tried to refine the simplistic concept of generalized cost for transit trips by including variables such as type of mode (*6*) (*7*), headways (*7*) or the crowding level (*8*). Regarding transit quality of service, Litman (*9*) proposes different concepts such as reliability, comfort or security. The 3rd edition of the Transit Capacity and Quality of Service

Manual (*10*) also provides a useful guide to determine the transit quality of service, taking into account service frequency, punctuality or passenger load.

Mode choice models could also be improved by considering the diversity of the alternatives available for a desired trip. This is the idea of Nassir et al. (*11*), for whom an important number of alternatives linking an origin to a destination brings value to a network. The authors were able to confirm their assumption, as they improved the accessibility modelling of San Francisco bike network, in considering not only the shortest path but several alternatives. This can also find its relevance by the fact that route preferences can vary across the population, by demographic group for instance (*6*).

Expectations and Perceptions of Montreal Transit Users

We analyze two surveys to illustrate the fact that public transit modelling needs to focus more on features other than time and cost.

The first one relies on expectations expressed by a panel of users conducted by the Montreal transit authority (STM) in 2014. STM operates four subway lines and 220 bus routes; its annual ridership is 417.2 million passengers in 2014. It should be noted that the panel is not perfectly representative of the users' population, as some socio-demographic segments are over-represented, such as elderly people and women. It includes also a larger proportion of regular users. Participants had to select their typical travel mode (metro, bus or both) and frequency of usage (regular or occasional). Then, they had to choose the five most important expectations regarding transit among a predetermined set of features. The results are presented below (Table 1).

As we can see, in both regular and occasional cases, barely all metro users select reliability and frequency as important expectations. Information, safety and overcrowding are also quite high in the list. For bus riders, frequency and punctuality are also largely mentioned, followed by overcrowding, driving behavior and seat availability.

The second survey was conducted by the Réseau de Transport de Longueuil (RTL); this company manages public transit service in the near South Shore of Montreal. The network counts 84 bus routes, carrying 35 million passengers each year. A web survey was conducted among residents who had previously participated in a phone survey on this subject. They were asked to choose between two hypothetical public transit options: 1) Walk more to bus stops where frequency is higher or walk less to stops where frequency is lower; 2) A longer trip with no transfer or a shorter trip with a transfer. The results are presented below (Table 2).

Clearly, the frequency is a more important expectation than walking distance. Also, potential users are willing to spend more time travelling in a single vehicle than having to transfer between lines.

TABLE 1 Number of Answers for Each Expectation (source: STM, 2014)

Metro expectations	Regular N = 1288	Occasional N= 444	Bus expectations	Regular N=1015	Occasional N=344
Reliability	1040	332	Frequency	863	246
Frequency	941	285	Punctuality	857	243
Information during service disruption	562	222	Overcrowding level	453	137
Safety	555	166	Drivers' departing, driving and stopping behavior	429	119
Crowding level	547	134	Seat availability	331	107
Transfer synchronization	395	128	Information on network disruptions	266	95
Cleanliness	335	126	Network coverage	260	90
Operating hours	305	119	Security	256	85
Temperature	290	117	Drivers' courtesy	249	79
Seat availability	281	98	Respect of road safety	224	72
Air quality	277	89	Fulcrum access	207	65
Escalators in operation	270	89	Information at stop	171	58
Availability of support or grab bar in vehicles	217	86	Cleanliness	167	56
Courtesy of staff	152	84	Temperature	156	41
Ease of orientation (signaling)	106	79	Air quality	92	36
Rolling smoothness	84	27	Drivers' information quality	58	21
Noise level	61	22			

TABLE 2 Answer Choices in Two Hypothetical Cases (source: RTL, 2013)

	Higher frequency	Walking less	I don't know	No transfer	Shorter trip	I don't know
Number of answers (N=403)	257 *(63.8%)*	91 *(22.6%)*	55 *(13.6%)*	236 *(58.6%)*	104 *(25.8%)*	63 *(15.6%)*

Existing Transit Quality of Service Measures

The perception of time in public transit has already been studied by many authors, among them Anderson (*7*). Her research gathers a large number of estimated perception times, scaled to in-vehicle time, from studies all over the world and in various contexts. The TCQSM (*10*) also provides a summary of average and range of time multiplier resulting from studies across different US cities. Scaled to in-vehicle time equal to 1, the average walking time is valued 2.2 (0.8-4.4

range), the average initial waiting time 2.1 (0.8-5.1 range) and the transfer time 2.5 (1.1-4.4 range). However, many studies show that travel time can be perceived as a useful time to conduct various activities (*12*).

To tackle the issue of evaluating the impact of vehicle loading, some authors tried to define a time multiplier coefficient which is function of the crowding level. Whelan & Crockett (*13*) conducted a study in rail network, and estimated two coefficients to measure the effect of passengers' density on the perceived time. A coefficient is defined for the seated passengers, another for the standing ones. Both grow with the crowding level. Van Oort & al. introduced a crowding function to multiply the in-vehicle time (*14*). It enables to consider both the discomfort related to seat unavailability and the impossibility to board due to overcapacity. The NHCRP Report 616 (*15*) also estimates the perceived in-vehicle time value related to the amenities at stops, including seat and shelter.

Other studies focus on transfer penalties, which accounts for the increased perceived time resulting from the reluctance of passengers to change lines. The TCQSM (*10*), propose a value of 12 to 17 minutes for each transfer. For Anderson (*7*) transfer penalties are segmented according to the type of modes involved in the transfer. Bovy & al. (*16*) found that better results were obtained when high frequency and low frequency transfers were differentiated. For reliability measures, the TCQSM (*10*) proposes a relevant method to classify schedule adherence. It takes on-time performances for low-frequency services and headway regularity for high-frequency services to assign a reliability level. Wood & al. tested two recent methods to evaluate the variability of travel time from a passenger's perspective, using data from fare boxes and vehicle geo-localization (*17*). Besides, in case of delays, Gooze & al. explain that real-time information can reduce the discomfort experienced by the user (*18*). Another aspect is addressed by Raveau & al. (*8*), which is the distortion of a transit route. A cost is thus implemented, following an equation depending on the angle between the desire line and the effective transit route, to evaluate the geometrical directness.

METHODOLOGY

The method proposed is a conceptualization of the aforementioned elements, namely the quality and the diversity of transit trip alternatives (Figure 1).

The initial travel demand is defined by an origin, a destination, and a time slot. We then use a trip calculator to generate a choice set of alternatives. A filtering step validates those using duration and similarity constraints. Then, indicators are developed for each alternative and grouped by category (time, cost, transfer, directness, performance). The expected outcome is a percentage score for these categories. We apply weighting coefficients to the categories, following their importance, in order to produce a quality score for each alternative. We rank the alternatives using this quality score. Finally, we compute general indicators of quality and diversity for the whole alternative package, using this ranking.

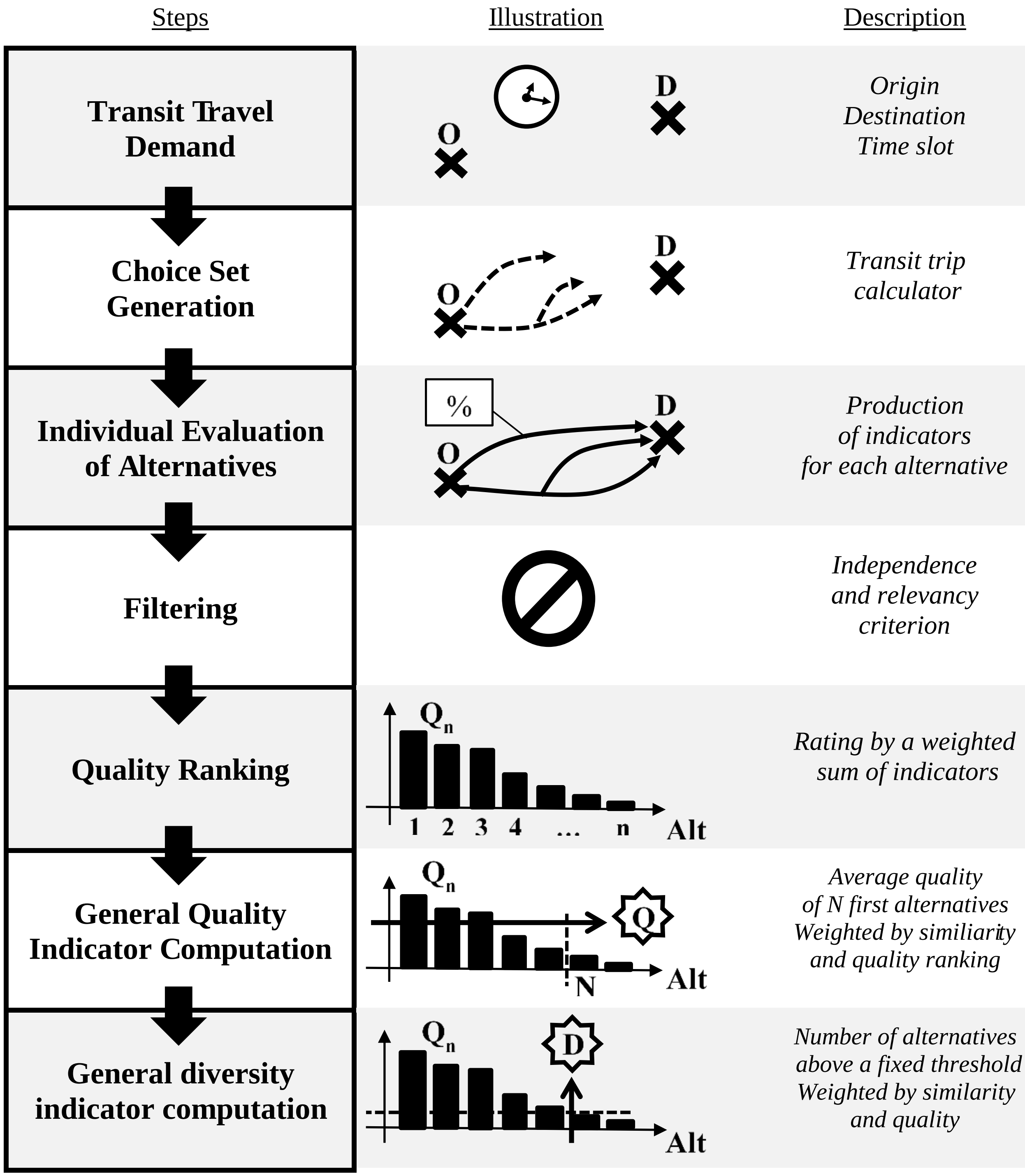


FIGURE 1 General methodological framework.

Individual Evaluation of Alternatives

The trip calculator may compute a very high number of alternatives; each one is characterized using a series of indicators:

- Access time *Ta* : time
- Waiting time *Tw* : time
- In-vehicle time *Tv* : time
- Walking time at transfer *Twalkt*: time
- Waiting time at transfer *Twaitt*: time
- Egress time *Te* : time
- Trip fare *C* : price
- Number of transfers *Nt* : integer
- Transfer cost *Ct* : float
- Angular cost *Cang* : float
- Maximum height *Hmax* : distance
- Hourly Capacity *Caph* : integer
- Gaps between stops *Stopkm* : float
- Independance level *in* : float

Time Indicators

Access and egress time refer to the walking time to and from a transit stop. Waiting time could easily be estimated using the typical assumption of half the headway, but some studies have demonstrated that it is only valid for high frequency lines. Indeed, for larger headways, passengers stop arriving randomly and plan their arrival based on the schedule. Luethi & al. (*19*) collected data during the peak period in the public transit of Zurich (Switzerland). Results showed that as the headway reaches 5 minutes, the median waiting time followed a logarithmic regression. Hence, we estimate waiting time using the following equation:

$$Tw = \begin{cases} \dfrac{headway}{2}, & headway \leq 5min \\ \dfrac{1.5}{(\ln 10 - \ln 5)} * \ln headway + 2.5 - \dfrac{1.5}{(\ln 10 - \ln 5)} \ln 5, & headway > 5\ min \end{cases}$$

This way, if the headway is over 5 minutes, *Tw* increases in a logarithmic way. The function is calibrated so that *Tw* is equal to 4 minutes for a 10 minutes headway.

Walking time at transfer considers the path that people have to travel by foot. This depends on the configuration of the transfer between lines (same platform, different levels, long corridors etc.). It is differentiated from the waiting time at transfer, which is the time spent at the platform or the bus stop.

Cost Indicator

The trip fare may vary according to the characteristics of the traveler (student, adult, senior etc.) and the fare package (10 trips, unlimited use for the evening, 3-days card, etc.). If the passenger owns a travel pass enabling unlimited trips, the cost is then considered as zero since it is perceived as a long-term expense.

Transfer Indicators

In transfers, the headway of the downstream line is of great importance as Bovy & al. (*16*) confirmed. Indeed, the more frequent it is, the smaller the consequences are if the transfer fails. The type of transfer is also to be taken into account: Anderson (*7*) showed that the modes involved in the transfer also have an influence. In addition to the number of transfers *Nt*, an extra transfer cost *Ct* is then considered for each transfer. It is define as:

$$Ct = 1 - \exp\left(\frac{-(headt)^2}{\beta t}\right)$$

where: *headt* is the headway of the downstream line involved in the transfer; *βt* depends on the type of transfer: -81/ln(0.8) if bus+bus; -81/ln(0.85) if bus+heavy mode; -81/ln(0.9) if heavy+heavy

This function has been determined so that the additional transfer cost lies between 0 and 1, and increases with the headway. It is calibrated so that the extra penalties are as follows:

- 0.1 for a transfer between two heavy transit lines and where the downstream line has a 10 minutes headway;
- 0.15 for a transfer between a bus and a heavy transit line and where the downstream line has a 10 minutes headway;
- 0.2 for a bus to bus transfer and where the downstream line has a 10 minutes headway.

Directness Indicators

Trip directness looks into the geometrical distortion of the path with respect to desire line, taking up the idea of Raveau & al. (*8*). If the trip includes one transfer or more, only the angular cost *Cang* is introduced. This one considers the fact that people have to deviate from the desire line (straight line from origin to destination) to transfer. *Cang* is computed according to Raveau's formulation:

$$Cang = \sum_{r} \mathrm{dr} * \sin(\frac{\theta r}{2})$$

where r is a route, dr the straight distance on route r, and Ѳr the angle between the residual desire line and the direction towards the next transfer (Figure 2(*a*)). If he trip has no transfer, only the maximum height Hmax is introduced. It is the maximum distance between the desire line and the route (figure 2(*b*)).

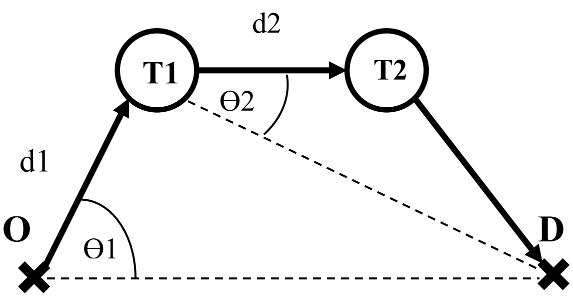


FIGURE 2(*a*): *Cang* indicator.

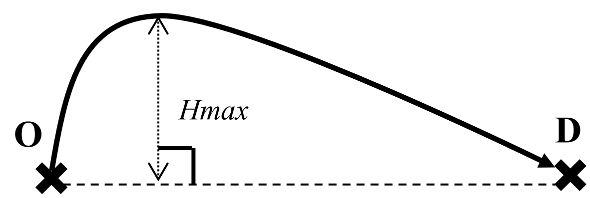


FIGURE 2(*b*): *Hmax* indicator.

Performance Indicators

The performance of the trip measures the "power" of each alternative. It addresses both practical concepts and perceptual features; it includes two indicators. *Caph* is the theoretical capacity of the route multiplied by its frequency (in passengers/hour). If the trip includes several routes, the indicator is weighted by the in-vehicle time for each route. Gaps between stops are also an important issue, as it can affect the perception a user has on the efficiency of a route. Indeed, an express service, which has limited stops, will improve commercial speed but also improve perception of performance. The corresponding measure is the average number of stops by kilometer *Stopkm*.

Other Indicators under Development

Other aspects should be considered in the evaluation of transit alternatives, like reliability and comfort. Nonetheless, these refer to more qualitative features, so that they are harder to evaluate. Besides, data rarely exist on such elements, making them more difficult to include in empirical analysis. This section discusses the way we will deal with this issue.

Reliability is a very important factor. The TCQSM proposes a method to measure it using categorical delay data (*10*). Wood & al. explore a method to evaluate reliability from the passenger perspective (*17*). It relies on the concept of passenger's buffer time, which is the extra time a user will plan in order to limit the consequences in case of delays. The estimation of such indicator requires data such as those outputted from smart card systems, which enables to monitor travelers' behaviors with respect to time of departure and trip duration. The advantage of this approach is that it provides a good estimation of the passenger's buffer time, whether by route or by origin-destination pair. This could be an excellent reliability indicator for a particular transit alternative.

Indicators focusing on comfort are also essentials. The level of crowding in a vehicle is not simple to estimate: data is rarely available, and the probability of finding a seat (as well as the density of passengers) varies along the route. One way to estimate these elements is to use a crowding function, as proposed by van Oort & al. (*14*). :

$$VC = \frac{L/_{Cseats}}{1 + {L - Cseats}/_{Ccrush - Cseats}}$$

where VC is the vehicle capacity, L is the passenger load, Cseats is the seating capacity and Ccrush the total capacity of the vehicle. The idea behind this formulation is to account for two types of crowding: the probability of seating, with the factor increasing from 0 if there is nobody inside the vehicle to 1 if all seats are occupied, and the global occupation of the vehicle where the factor reaches 2 when the number of passengers equals the capacity.

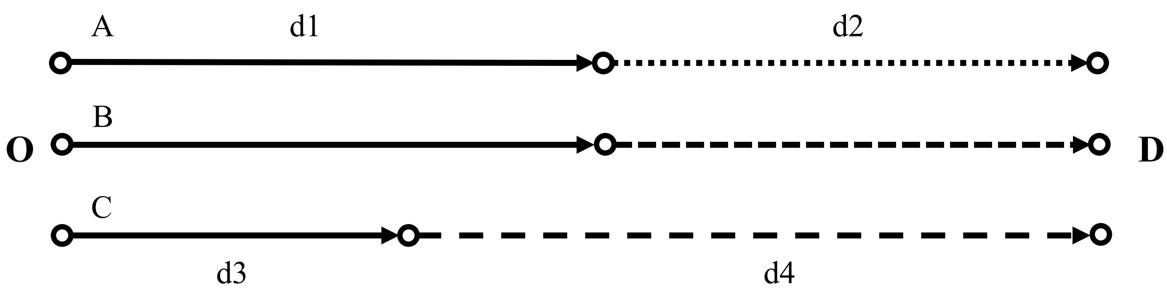
Other comfort-related features can be considered (amenities at stops, quality of the pedestrian access to stops) and should be explored.

Independence Level

As alternatives may share sections of transit routes, it is necessary to determine how different they are. Ben Akiva & Bierlaire first introduced this concept with the definition of a Path Size (*20*). The following equation takes up their idea, and calculates the independence level of each alternative n:

$$in = \frac{1}{dn} * \sum\nolimits_{s} ds * \frac{1}{ns}$$

where dn is the total distance of the routes of alternative n, s is a segment of alternative n, ds is the length of the segment s, ns is the number of alternatives using the same segments s (Figure 3).



$$iA = \frac{1}{d1 + d2} * (\frac{d3}{3} + \frac{d1 - d3}{2} + d2)$$

$$iB = \frac{1}{d1 + d2} * (\frac{d3}{3} + \frac{d1 - d3}{2} + d2)$$

$$iC = \frac{1}{d3 + d4} * (\frac{d3}{3} + d4)$$

FIGURE 3 Example of independence level estimation for alternatives A, B and C.

Filtering

Typically, transit trip calculators solely output the best alternatives. Indeed, they usually include constraints which enable to list only feasible routes. We have identified the constraints that need to be set to filter the relevant alternatives:

- There needs to be a minimum number of stops for a route segment to be included in a path; this number is chosen to be two for any kind of transit mode.
- A maximum of transfers needs to be fixed in order to select the acceptable transit paths; alternatives should not include more than three transfers.

- Each time component needs to be topped: maximum access or egress time are 20 minutes, maximum walking plus waiting time at transfer is 30 minutes; in our study, we also suppose that only alternatives with duration less than twice the duration of the shortest path are selected.
- To be considered in our research, alternatives must have an independence level beyond 20%. This matches with an alternative sharing all of its sections with 4 other alternatives.

Quality Ranking

Percentage Rating

To compare the different individual quality indicators, we integrate them through a percentage score, estimated for each category (time, cost, transfer, directness and performance). Weights are used if the category relies on several indicators. Moreover, each indicator is examined with respect to a reference value while a reference function allows estimating the percentage score. Details are presented in Table 3:

TABLE 3 Weights, References and Functions for the Percentage Rating (na=not applicable)

Categories	**Time**					
Indicators	Ta	Tw	Tv	Twalkt	Twaitt	Te
Weights	βta	βtw	βtv	βtwalkt	βtwaitt	βte
References	2	1.5	Dae/35*60	0	0	2
Reference Functions	$\exp(\ln(0.5) * (\frac{(\sum Ti*\beta ti - \sum Tref*\beta\, ti)^2}{2*\sum Tref*\beta\, ti})$					

Categories	**Cost**	**Transfers**		**Directness**	
Indicators	C	Nt	Ct	Cang	Hmax
Weights	na	1	1	na	na
References	βC	0	0	0	0
Reference Functions	$\exp(\frac{\ln(0.5)}{0.04} * \left(\frac{C}{\beta C}\right)^2)$	$1 - \frac{Nt + Ct}{4}$		$\exp(-\frac{Cang^2}{7})$	$\exp(\ln(0.5) * \frac{Hmax^2}{2})$

Categories	**Performance**	
Indicators	Caph	Stopkm
Weights	βCaph	βStopkm
References	35000	1
Reference Functions	$\frac{Caph}{35000}$	$\frac{1}{Stopkm}$

For the time category, the beta coefficients represent the weight given to the different indicators. They account for the travelers' perception of each component depending on his socio-demographic characteristics. The reference for *Tv* is the time a metro takes to cover the distance between the origin and destination stops (*Dae)*, at 35km/h. The reference function is set to score 50% when the total perceived time equals three times the total perceived reference time. For the cost, the reference also depends on the type of traveler, and his value of time according to the trip purpose. The function equals 50% when the ratio *C* on βC is 0.2. For transfers, the number of transfers added to the extra cost must not be over 4. The reference for the *Stopkm* is set to 1, but if the alternative has less than one stop per kilometer, the score is automatically set to 100%.

Quality Score

Once each alternative has a percentage score for the different categories, it is necessary to compute an overall quality score for each one. To proceed, the categories must be weighted. Parameters vary across the travelers to account for their preferences. The corresponding weighting factors are noted αtime, αcost, αtransfer, αdirectness and αperformance. A weighted mean on each category enables to compute a percentage quality score for each alternative. Ranking is then possible using all quality scores.

General Quality Indicator

To evaluate the whole set of available alternatives, a general quality indicator is computed. For this, N alternatives are chosen, starting with the one with the highest quality. This number remains constant each time the method is repeated. Then, the average quality of these N first alternatives leads to a general quality indicator for all of the available alternatives for a particular trip. If there is less than N alternatives, null values are used for each missing alternative. This average value is weighted by the independence level. There is also a weight related to the ranking of each alternative, so that better alternatives have more importance in the final value of the indicator. This also reduces the incidence of having less than N alternatives in the computation.

General Diversity Indicator

For the general diversity indicator, a threshold enables to select only the alternatives above a predetermined level of quality. Then, the sum of the independence level, multiplied by the individual quality of each selected alternatives is computed. Consequently, the diversity indicator not only considers the number of alternatives available, but also takes into account the fact that some may be more or less similar. The individual quality is also considered to give more weight to better alternative.

CASE STUDY

To test the method, ten Origin-Destination (OD) pairs are selected. All of them share the same destination (Polytechnique School). The ten origins and the destination are shown in Figure 4. The different transit alternatives are obtained using the online transit trip calculator from Google Maps, for a weekday, departing between 6:00 AM to 9:00 AM.

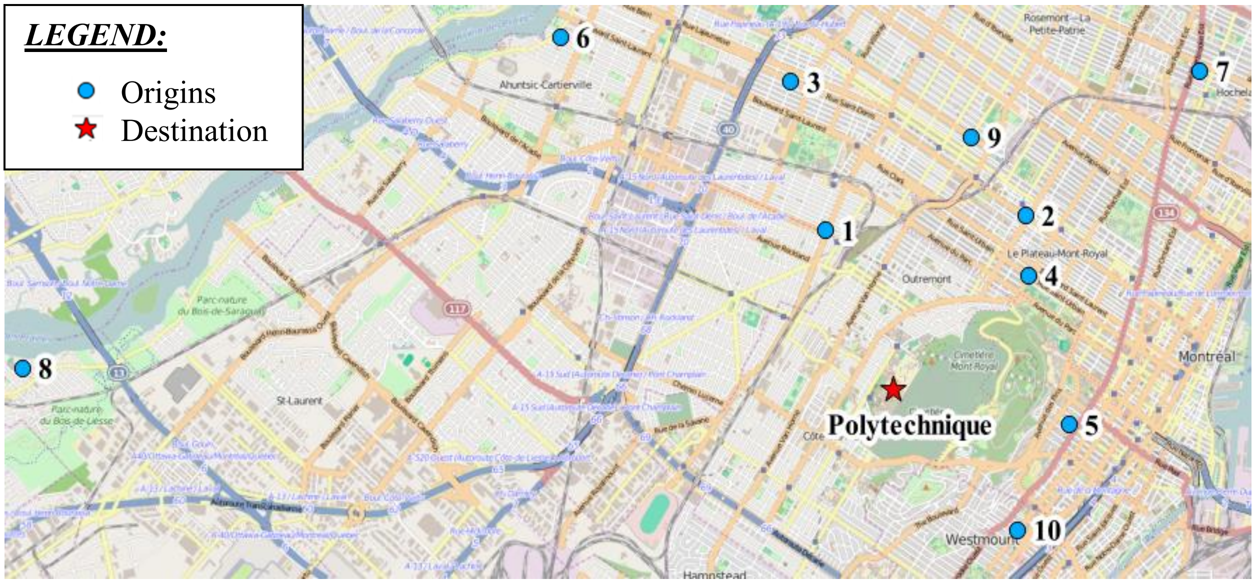


FIGURE 4 Location of the ten origins and the destination (number of alternatives at the right of each origin).

The method is first implemented on a reference case, defined by the coefficients presented in the Ref case in Table 4. They are fixed so that each quality features is equally accounted for. Then, the quality and the diversity is computed for the ten OD pairs using these coefficients, a quality threshold of 20% and a fixed number of alternatives (N=5). The corresponding quadrant is presented in figure 5. First of all, we can see that the quality indicator is between 40 and 70 % for the pairs, and the diversity between 0.5 and 3. It is normal not to have a score between 1 and 10 for the diversity, as the indicator also takes into account the independence level and the quality of each alternative. Another interesting fact is the positive correlation between diversity and quality. One the one hand, the diversity indicator gets richer with the individual quality of each alternative, and so on with the global quality. On the other hand, an OD pair with a low number of alternatives, typically under 5, has a low quality score, because the missing alternatives are set to 0% of quality. Then, the diversity is also low. We also notice that the diversity indicator does not follow the number of alternatives. For instance, the OD pair with 8 alternatives has a lower diversity than the one with 4 alternatives. This is due to the fact that this indicator considers the independence and the individual quality of the alternatives. It confirms that the indicator is able to account for the variety of alternatives. Three other sets of coefficients are used to observe how the indicators vary for the same OD pairs. The three experimental sets are described in Table 4. The corresponding quadrants are illustrated in figure 5.

TABLE 4 Coefficient Sets Used For the Test

	Betas coefficients									Alpha coefficients				
Case	Ta	Tw	Tv	Twalkt	Twaitt	Te	C	Caph	Stopkm	Time	Cost	Transfer	Directness	Performance
Ref	2	2	1	2	2	2	20	0.5	0.5	2	2	2	2	2
A	2	2	1	**3**	**3**	2	20	0.5	0.5	1	1	**3**	1	1
B	1	**3**	1	2	2	1	20	**0.7**	**0.3**	**3**	1	1	1	**3**
C	2	2	1	2	2	2	**100**	0.5	0.5	2	2	2	2	2

The second quadrant represents the test where coefficients have been chosen to reflect reluctance to transfers. The perception of the walking time and the waiting time during transfer is three times the perceived in-vehicle time. Also, the coefficient for the category transfer is three times the value of all the other categories. Some OD pairs have a significant different position in the quadrant than the reference situation. The one with 4 alternatives went from 60% to 70%, meaning this pair have fewer transfers, or at least efficient ones. On the contrary, the one with 9 alternatives has a lower quality.

The third quadrant highlights frequency impact. The indicator of waiting time is three times larger than in-vehicle and access/egress times. The hourly capacity is weighted to 70% of the performance category. Then, the time and performance are set to three times the weights of other categories. The results show differences in diversity and quality, compared with the reference case. For example, the OD pairs with 7, 9 and 10 alternatives have quite the same position in the quadrant. In the reference case, they were separated with barely 10% of quality and 0.4 of diversity. Those pairs are thus evaluated with quite the same measures.

The last quadrant relate to value of time (VOT). The higher the VOT is, the more indifferent a person is to travel time. The coefficient of the cost indicator is set to 100 rather than 20 (reference). Generally, the quality indicator increases for all pairs since the score for cost category increases. Some OD pairs, like the one with 8 alternatives, have important increases in quality (app.8%). This is the result of high costs for some of the alternatives involved, which are then less penalized.

FIGURE 5 Quality and diversity of the 10 OD pairs with different coefficients.

CONCLUSION

This paper proposed a method to identify the quality and the diversity of the transit alternatives. This method allows comparing these indicators for various OD pairs, and has the advantage of looking at specific OD pairs, not aggregate values. Indeed, it can be applied in various contexts, with different data and public transit networks. It is adaptive in two ways: 1) new indicators can easily be incorporated in the estimation of individual quality and the reference value can be changed as well and 2) the method includes a lot of weighting factors that can be modified to emphasize some aspects. The high number of parameters to define and weight could be seen as a shortcoming. However, we believe that nowadays, with more and more data available from automated fare collection systems, passenger information systems and automatic vehicle location systems, these parameters are easier to calculate and calibrate at the individual level.

We identify various research perspectives: development of new indicators related to qualitative features, improved procedures to compute relevant transit alternatives, validation using large-scale samples and inclusion in travel behavior models.

Finally, the quality and diversity indicators can be used as explanatory variables in mode choice models to validate whether it helps understand mode choice.

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