WHAT IF THE NETWORK WAS DESIGNED BY THE DEMAND AND HOW MUCH DOES IT COMPLY WITH THE SUPPLY?

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ABSTRACT

Network design has been qualified as the most important step in transport planning. Since the transportation supply is usually designed to fulfill collective demand, its structure should trace the Origin and Destination (OD) flow as a reflection of the ultimate goal of travelling: moving between the origin and destination points. Traditionally, the supply’s spatial characteristics were examined from specific angles and the collective demand standpoint was generally a neglected angle.

The paper examines the relevance of using OD flow, represented by the demand corridors, as a reference unit in supply design. Therefore, an approach was proposed and a set of four indicators that incorporate the demand corridor as a comparison unit were constructed and adapted. The indicators assess different facets of the supply structure with respect to the demand flow through quantifying the distortion, remoteness and supply shape. The applicability of this approach was tested through the identification of demand corridors from a set of disaggregated data from the Montreal 2013 OD survey.

The result demonstrates the possibility to evaluate the supply based on its level of compliance to the demand flow and it illustrated the potential of demand corridors as relevant tools for transportation planning, and in the decision-making processes in which an indicator is needed to evaluate the actual or the planned supply. Finally, the approach proposed in this paper opens the door for future areas of research regarding the use of the demand corridor as a reference unit, the formulation of new indicators, and a global index to assess the quality of the supply structure.

Keywords: Demand corridor, Network design, Network structure, Network typology assessment, Transportation planning
INTRODUCTION

The supply should trace the Origin and Destination (OD) flow which corresponds to the ultimate goal of travelling: moving from the origin point to the destination point. However, the identification of the mobility flow may not be always obvious to planners and therefore network design, which constrains the flow, may not be optimal (1, 2).

Still, the development of new data collection methods and sources, which has led to massive amounts of OD information and stimulated development of new data treatment techniques, has brought new opportunities to design a supply in line with the mobility flow; for example, Rao et al. (3) identified and visualized major urban transportation axes using aggregated OD data and a data-mining method; while Pucci et al. (4) extracted OD pairs from mobile phone data and then mapped urban movement patterns. Furthermore, some studies (5, 6) have proposed to use major OD mobility axes, also called demand corridors, as a reference unit or as a tool in supply design and improvement.

However, the use of demand corridors in supply design lacks a well-structured approach using indicators benefitting from the spatial characteristics of demand corridors.

One of the main objectives of the present study is to examine the relevance of using the demand corridor as a reference unit in supply design. Furthermore, this study constructs and adapts some indicators that incorporate demand corridor as a “fair” comparison unit to assess the adequacy of transportation supply structure with respect to the demand.

The remainder of this study is organized as follows. The following section provides a review of the supply structure measures. The third section presents the research methodology and proposes an approach to assess the supply structure; while the fourth section tests the applicability of the proposed approach. The last two sections discuss the advantages and limitations of this study, and provide a general conclusion.

RELATED WORK

Many researchers (1, 7) have described network design as the first and most important step in public transport planning. Methodologically speaking, the individual’s ultimate goal is to travel from a given origin to a given destination; therefore, network structure should follow the direct line connecting the origin and destination points, which is called a desire line.

Several measures benefit from desire lines to evaluate the network structure and to qualify the travel experiences, including the distortion (tortuosity), the maximum height, and the angular cost indicators (8-10). The distortion indicator (DI) is defined as the ratio between the trip itinerary distance and the desire line distance; this ratio indicates the additional traveled distance from the shortest path. The maximum height indicator (Hmax) expresses the “remoteness” experienced using the supply and it is defined as the greatest perpendicular distance between the trip itinerary and the desire line; while the angular cost gives an indication of the route’s directness by measuring the angle between different route segments and the desire line.

Furthermore, other measures benefit from graph theory and social science to evaluate the network structure performance; for example, the Pi index (9) is used as an indication of network development (complexity) level; whereas others (11, 12) have measured network vulnerability or robustness through assessing the network connectivity and reachability.

In the available literature, we observed three recurring elements: the use of the desire line as a reference unit to assess the network’s disadvantages at the individual level, the absence of
reference unit at the collective level, and the lack of metrics reflecting how well the supply structure responds to the collective demand (12).

Since the transportation supply is usually designed to fulfill collective demand, the demand corridors, which encapsulate individual desire lines, could be used as a reference unit to develop some useful indicators that assess the supply structure. With this in mind, a corridor identification approach should be adopted and a set of indicators should be defined accordingly.

RESEARCH METHODOLOGY

The proposed approach builds on the concept of demand corridors to assess the supply structure through the identification of demand corridors and the analysis of the supply structure’s weaknesses from the collective demand standpoint.

Corridor Identification

Only a few tools can be found in the literature to identify demand corridors from desire lines. Bahbouh et al. (6) proposed an algorithm, called TraClus-DL, designed to identify demand from disaggregated OD data. The algorithm requires the definition of four simple parameters adapted to transportation planning: the minimum number of similar desire lines required to create a corridor (min_weight); the screening radius (max_distance); the maximum accepted angle between desire lines within a corridor (max_angle); and the segmentation length (segment_length).

TraClus-DL segments all desire lines into equal segments in reference to segment_length and then identifies similar groups of segments in reference to max_angle and to max_distance; if the number of segments in a group satisfies the min_weight, the algorithm will identify a corridor. The TraClus-DL results are sets of small corridors; the connection of consecutive small corridors leads to long demand corridors (axes). TraClus-DL links the inputs to its outputs offering the possibility to conduct deep analyses at the corridor level; more information about the algorithm’s functionality and parameters are available in the literature (6).

Structure Analysis

The demand corridor could be seen as the collective equivalent of a desire line. Thus, an adaptation of the existing indicators is needed to fit the demand corridor concept.

The adaptation should consider two issues. First, demand corridors and supply corridors may not start and end at the same points. The second issue concerns the representability, as the demand corridor represents a group of “similar” desire lines that may start and end at different points (5). The first issue was tackled by adding a penalty corresponding to the gap between the demand and supply corridors to prevent small supply to be considered more efficient than a longer demand corridor. For the second issue, we used the volume of the trips (e.g. passenger-km) instead of the traveled distance (e.g. km) to reflect the magnitude of the distance unit. The proposed indicators, clarified in Figure 1, are the following:

- The collective distortion indicator (CDI) is defined as the ratio between the demand corridor volume and the supply corridor volume. The volume is expressed in (passenger-km) to reflect the traveled distance and the number of trips associated to the distance unit.
In addition, two values were added to reflect the “non-efficiency” of the supply if it starts or ends in different points than the demand corridor. The CDI is a ratio of a value greater than or equal to 1, the greater the value is, the poorer the supply’s performance is from the collective demand standpoint. Equation 1 expresses the calculations:

$$\text{CDI} = \frac{\text{supply corridor volume}}{\text{demand corridor volume}} + \alpha + \beta \quad (1)$$

where:

- \(\alpha\) : penalty (\(\alpha \geq 0\)) if supply starts at different point than demand corridor; and
- \(\beta\) : penalty (\(\beta \geq 0\)) if supply ends at different point than demand corridor.

In our study, \(\alpha\) and \(\beta\) were estimated as clarified in Figure 1.

- The collective remoteness indicator (CRI) calculates the surface encapsulated by demand corridor and the supply corridor (concave hull). We opted to use the surface instead of the maximum height as it expresses the total remoteness of the supply from the reference unit. To express the collective demand, the concave hull was partitioned and each portion of the concave was associated to the number of trips that it represents. The CRI is a value greater than or equal to 0, the greater the value is, the more the supply axis deviates from the collective demand axis. Equation 2 expresses the calculations:

$$\text{CRI} = \sum_{i=1}^{p} \text{surface}_i \times \text{Trips.surface}_i \quad (2)$$

where:

- \(p\) : number of partitions;
- \(\text{surface}\) : partition surface; and
- \(\text{Trips.surface}\) : number of trips associated to the partition.

Figure 1 clarifies the collective distortion indicator and the collective remoteness indicator concepts.
In addition, the supply shape can be assessed from the demand corridor standpoint. The following are some of the available measures (trajectory similarity) that can be used to rank the supply shape:

- The Longest Common Subsequence Similarity (LCSS) approach was used in the literature to assess the similarity level between two trajectories (13). We refer to the minimum value required to consider two trajectories 100% similar using LCSS approach as \( \text{LCSS}_{100\%} \). In other words, \( \text{LCSS}_{100\%} \) represents the minimum radius allowing each point from the demand to be reach, at least, one point from the supply. The \( \text{LCSS}_{100\%} \) could be considered as a way to score the remoteness and the difference in distances between two forms. The less the value is, the more similar the trajectories are to each other.

- The *Overall similarity index* (OSI) is built on the work of Lee et al. (14) who proposed a formula to measure the similarity between two complex trajectories. The formula computes and aggregates the perpendicular distance \( d_\perp \), the parallel distance \( d_\parallel \), and the angle distance \( d_\theta \) in one equation.

\[
\text{CDI} = \frac{\text{supply corridor volume}}{\text{demand corridor volume}} + \alpha + \beta
\]

\[
\alpha = \frac{t_p}{\text{demand corridor volume}} \quad \beta = \frac{10s}{\text{demand corridor volume}}
\]

The OSI is another indicator to score the similarity between the supply and the demand. The less the value is, the more similar the trajectories are to each other. More information about the formulation of each distance can be found in the literature (14).

**EXPERIMENTAL SECTION**

The experimental section aims to clarify the applicability of the proposed approach with the use of real data. Hence, we applied the proposed approach to a set of disaggregated data from the Montreal 2013 OD survey.

In Montreal such surveys, carried out every 5 years since 1970, gather detailed information...
about daily trips during a typical weekday of some 4.5% of the population. One important output of the survey is a disaggregated OD matrix that contains detailed information about the trips and socioeconomic details. More details on these surveys can be found on the website of the Montreal Metropolitan Transportation Agency (15).

For this study, we use a set of 6,659 observations representing 174,974 trips made within the Island of Montreal using only the metro (subway). Each observation is weighted by the number of trips it represents. The metro network within the Island of Montreal consists of the Blue, Green, and Orange Lines, which have a total of 63 stations. Figure 2 presents the study area, the observed desire lines and the metro network.

The variables used in this study are:

- IPERE: observation unique identification;
- D_FEXP Expansion factor (sampling weights) that estimates the number of trips represented by each observation;
- D_ORIXCOOR, D_ORIYCOOR: origin x, y coordinates (Modified Transverse Mercator coordinate system, North American Datum 83); and
- D_DEXCOOR, D_DESYCOOR: destination x, y coordinates (Modified Transverse Mercator coordinate system, North American Datum 83).

**FIGURE 2 Island of Montreal with subway network and observed desire lines.**
TraClus-DL was applied to all OD pairs using a `min_weight` of 400 trips, which was considered to be a reasonable starting density level within a `max_distance` of 500 meters (total width of 1000 meters) and with a small maximum allowed angle (`max_angle`) of 2.5°. For the segmentation, a `segment_length` of 300 meters was used to obtain reasonable granularity. It should be noted, depending on planners’ objectives, that other parameters could be proposed, tested and analysed.

The TraClus-DL outputs, illustrated in Figure 3 (a) and (b), are sets of small corridors, where each corridor carries information about the number of trips clustered and trip features. For better visualization, the consecutive corridors with the same direction were connected as presented in Figure 3 (c) and (d). In total, thirteen long corridors were identified, among them six unidirectional and seven bidirectional corridors.

![TraClus-DL outputs](image1)

![Supply network and demand corridors](image2)

![Main demand corridors (long corridors)](image3)

![Main demand corridors and supply network](image4)

**FIGURE 3** Demand corridor identification results.

The comparison between the supply corridors (metro lines) and the demand corridors was done by using collective distortion indicator, collective remoteness indicator, LCSS_{100%} and Overall similarity index.

In this paper we present the result of one direction of corridor 9 (direction south – north) as it carries a sufficient number of trips (2,228 trips) to clarify our approach efficiently and simply. Figure 4 (a) and (b) presents the corridor 9 south-north.
In this study, we do not have information about the start and end stations. Thus, each trip (origin and destination) was assigned to the closest metro station (threshold distance) and the shortest itinerary between stations were identified to estimate the supply load profile. Figure 4 (c) and (d) presents the load profile of the supply and the demand axes and convex hull respectively (used in the CDI and the CRI calculations).

To compute LCSS$_{100\%}$, the supply and the demand axes were divided into points. As illustrated in Figure 4 (c), the distances between all points were calculated to determine the minimum radius allowing each point from the demand corridor to reach, at least, one point from the supply.

The computation of OSI required the segmentation of the supply axes into 4 trajectories while the demand corridor remains as one trajectory (Figure 4 (f)). The similarity of each trajectory to the demand corridor was calculated; we noticed that the perpendicular trajectories (number : 1, 2, and 4) have a much higher OSI value (>10000) than trajectory 3, due to their small portion along the main axis we considered only the similarity value of trajectory 3 in the OSI value.

The structure assessment results of corridor 9 are presented in Table 1.
FIGURE 4 The corridor 9 analysis.
TABLE 1 Corridor 9 structure assessment results

<table>
<thead>
<tr>
<th>Collective distortion indicator</th>
<th>Collective remoteness indicator</th>
<th>Overall similarity index</th>
<th>LCSS$_{100%}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.35</td>
<td>5227.07</td>
<td>2380.00</td>
<td>1850.00</td>
</tr>
</tbody>
</table>

The results give some information about the supply’s spatial characteristics from the collective demand standpoint. First, the supply generates an additional amount of passenger-km (estimated at 35%) than the theoretical reference unit. This information is useful for decision makers looking to set improvement targets. Second, the CRI value quantifies and expresses the magnitude of the overall remoteness, in the design and planning process this information may help to rank different designs in order to select the one that best matches the demand. Furthermore, the similarity value (LCSS$_{100\%}$ and OSI) gives a general idea about the supply shape’s similarity to the demand flow, allowing one to rank shapes in the design process. The difference between similarity results can be explained by the variation of the equation in each one; the LCCS considers the directness too.

Still, in a global study, where the supply network is compared to the demand corridor network, those indicators may help in the prioritization of intervention actions to focus on the supply that differ the most from the demand.

DISCUSSION

Benefiting from the demand corridor as a reference unit, the paper provides new insights into the possible ways of assessing the spatial characteristics of the supply structure. In contrast to the traditional approaches, where supply vulnerability or individual impact are measured, the use of the demand corridor as a reference unit reflects the collective demand standpoint and offers the possibility to rank supplies based on each supply's level of compliance to the demand flow.

First, we proposed an approach, consisting of two main steps, to assess the supply. The first step benefits from new computation methods where demand corridors can be identified away from administrative and operational limits. Then, we proposed and adapted some indicators to fit the concept of the demand corridor and to reflect the spatial characteristics of the supply. The collective distortion indicator evaluates the magnitude of the supply length and reflects its efficiency (from the demand perspective). The collective remoteness indicator quantifies the remoteness of the supply. The overall similarity index and LCSS$_{100\%}$ allow one to rank different shapes in the design process.

Second, we clarified the application of our approach using a set of disaggregated OD data. Even if we used OD pairs that are already linked to a specific supply (metro network), the use of all available OD data is possible. Then, we selected TraClus-DL because of its ability to identify demand corridors from desire lines. Other algorithms may be applied and tested. However, each algorithm has its own structure, inputs, and equation.

The corridor identification parameters were not discussed explicitly in this paper. We
emphasize the fact that parameter selection may vary depending on the study and planners’ objectives. However, we identified and mapped demand corridors using different parameters to illustrate the parameter selection effects. Figure 5 illustrates the effect of reducing the required \textit{min\_weight} from 400 trips to 300 trips. Still, we refer to relevant literature for an exhaustive view of effects of parameter selection and TraClus-DL’s advantages and limitations (6).

![Image: Demand Corridor Illustration](image.png)

**FIGURE 5** The effect of the choice of parameters on demand corridor identification.

Furthermore, the results for one corridor were presented and discussed. Each indicator reflected a side of the spatial structure and benefited from the demand corridor as a reference unit, thus comparing and ranking different forms of the supply becomes possible. In our case study, the metro network is a fixed infrastructure. Accordingly, the proposed approach could be helpful in the assessment of the current supply and in the design of new lines or extensions. Other services (e.g. bus) may benefit from the demand corridor approach to adjust the path and to minimize the gap between the supply and the collective demand flow. In addition, the gap analysis may point to important inefficiencies due to some physical, environmental, political or operational constrains.

We believe that the comparing of supply networks to demand corridor networks (as a whole) provides additional benefits to the supply design as it may involve the integration of further spatial issues such as the extent, accessibility, and connectivity of the network. However, we argue that the integration of the temporal dimension, to reflect mobility dynamics, is an important component in a large scale study.

Finally, we demonstrated the possibility of using the demand corridor as a reference unit. Yet, further indicators should be studied and their role in a global quality index should be examined profoundly. We argue that an indicator’s weight in a global index must be examined in line with the demand characteristics and the local context.

**CONCLUSION**

The paper goes beyond using the demand corridor as a visualization tool, it proposes to use demand corridors as a reference unit to evaluate the quality of the supply structure. Therefore, indicators were proposed to assess the length, the remoteness, and the overall form of the supply.

The case study clarified the application of the proposed approach and it illustrated the potential of demand corridors as relevant tools for transportation planning, and in the decision-making process. The application of the approach in a real-life scenario showed its practicality and the ability to quantify the supply quality, which can be used to guide future infrastructure planning and decision-making.
making processes in which an indicator is needed to evaluate the current or planned supply. 
Finally, the approach proposed in this paper opens the door for future areas of research regarding the use of the demand corridor as a reference unit, the formulation of new indicators, and a global index to assess the quality of the supply structure.

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