Zoning Decisions in Transport Planning and their Impact on the Precision of Results

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ABSTRACT

In most transport planning studies one of the first steps is the definition of a zoning scheme with which the study area is divided and the corresponding space is disaggregated. There are no clear rules on how to carry out this operation in an optimal way, and the dominating practice is to do it based on experience, trying to mix a certain degree of within-zone homogeneity and the convenience of using administrative borders as zone limits. This paper starts by looking at the potential errors generated with this operation, both at the statistical level when trip matrices are based on sampling, and at the geographical level when all trips starting or ending in a zone are assumed to do it at its centroid. It then presents a set of quality criteria for a general zoning scheme and an algorithm that constructs an initial zoning based on a sample of geo-referenced trip extreme points and improves it in successive steps according to those criteria. A case study based on the Mobility Survey for the Lisbon Metropolitan Area is included to illustrate those steps and the improvements achieved in each step. The magnitude of those improvements is very significant and shows that more attention should definitely be given to this initial process in the transport planning studies.
INTRODUCTION

The definition of a zoning scheme, with which the study area is divided and the corresponding space is disaggregated, is one of the first and more critical steps in most transport planning studies. In the past, little attention has been given to the task of establishing Traffic Analysis Zones (TAZ) relative to other elements of the modeling process. Literature review reveals only general information and guidelines on how zoning systems are defined.

Along four decades of research, the scientific literature has established some guidelines and constraints to TAZ definition. In this section a complete set of the constraints collected from the literature is presented and some contradictions and difficulties in their implementation are discussed.

These constraints or rules are:

- Homogeneity contributes to the improvement of the estimates of trip generation and the reduction of intra-zonal trips for various trip purposes (1-7).
- Contiguity and convexity of zones improve the estimates of O/D matrixes and ease the location of the TAZ’s centroid (3-6).
- Compactness of TAZs’ shapes improves the estimates of O/D matrixes (1-7).
- Exclusiveness (no doughnuts or islands) eases the location of the TAZ’s centroid and the trips assignment to zones (3-6).
- Uniqueness and completeness prevent TAZ from duplication and omission (3-6).
- Equity in terms of trip generation is considered to obtain diverse trip assignment so that every network segment has a chance to get loaded (3-6).
- Adjustment of TAZ boundaries to political, administrative or statistical boundaries is important since the census bureau provides numerous and high quality demographic data. The advantage to match TAZ with census boundaries is strong from the data collection point view (1-7).
- Physical geographic separators placed on territory as railways, rivers etc., as well as common urban mobility barriers must be respected (3-6).
- Decision maker’s preferences are considered in determining the number of TAZs (3-5), (7).
- Main roads as zone boundaries should be avoided, because this increases considerably the difficulty to assigning trips to zones, when these originate or end at a zonal boundary (7).
- Zones size must be such that the aggregation error caused by the assumption that all activities are concentrated at the centroid is not too large (geographical precision) (7).
- Minimization of intra-zonal trips minimizes the information loss in the space disaggregation process (1), (9).
- Maximization of the statistical precision of the estimation of the O/D matrix cells (10).

It is in fact very difficult to give equal consideration to and implement all the above criteria in a single process of TAZ design. This is because some rules contradict other rules (5-6). The distributions of population and employment, in fact, are at odds spatially in
metropolitan areas. If only one dominant type of land use, for example, is allowed, it most likely becomes difficult to obtain compact and convex shapes for all zones. With diverse levels of intensity of land use and population, equal trip generation ends up in different TAZ sizes. Obviously it is easy to keep homogeneous land use for small, but not for large zones. To obtain convex shapes of TAZ, the homogeneity criterion will have to suffer to some degree. This is true for compactness too (4).

Some of these rules are a consequence of the consideration of a fixed zoning system along time and for different study scales and purposes. In the scientific literature it is considered that transport demand modeling requires a constant spatial data aggregation in TAZ along all the process, from the data collection process to trip assignment step (2).

An implicit constraint to TAZ definition, normally not mentioned, is the most restrictive of all the constraints, due to the impossibility to know at the data collection process all the future uses of the data set. The imposition of TAZ homogeneity for a specific variable (e.g. car ownership) and the number of zones established can have a deep impact in the modeling results, making the use of one specific data sample unfeasible in some studies.

The problem of the number of zones can be solved through the development of a hierarchical zoning system, as in London Transportation Studies (7), where subzones are aggregated into zones which in turn are combined into districts, traffic boroughs and finally sectors. This facilitates the analysis of different types of decisions at the appropriate level of detail. Hierarchical zoning systems benefit from an appropriate zone-numbering scheme where the first digit indicates the broad area, the first two the traffic borough, the first three the district, and so on (7).

But predetermined zoning systems do not take into account the ongoing changes of land use (spatially and temporarily), that can deeply affect the TAZ homogeneity and compactness, producing significant misestimates of trip generation and O/D matrixes (10).

These ongoing spatial and temporal land use changes point out that current traffic management models, sometimes based directly on the results of the data collection process, suppressing the trip generation and distribution steps of the travel demand classical model (4), should use a different zoning system from the forecasting transportation demand models (11).

Zoning systems of forecasting transportation demand models should be based on the municipality site plans, development sites or community plans, using different detail scales depending of the study scale and purpose, where land use patterns are pre-determined or, at least, establishing ranges for the different land uses, thus enabling to set up for the study time scale, a more accurate zoning system than the present one (12).

Municipality sites plans are not commonly developed using administrative or statistical land units like census track or census blocks (12). This fact conflicts with the spatial constraint to TAZ definition, considered as main constraint for the majority of the scientific research: the adjustment of TAZ boundaries to political, administrative or statistical boundaries (5), (7), (13). The census data disaggregation problem was noticed by several authors, e.g. (14), and several overlaying methodologies were developed in order to solve it, e.g. (15), although scientific literature remains avoiding it.

A better solution to the data collection zoning system constraint is the development of sampling processes in which the trip extremes of each trip are geocoded. These data collection (sampling) process requires the establishment of an initial zoning system, as all the other data collection processes, for the definition of statistical strata and computation of expansion coefficients of each survey trip (7), but after the conclusion of this process, travel
data is not attached to any zoning system, only to their geospatial coordinates (16). Each study that uses this database can then develop a new zoning system that makes a better fit to the study scale and goals, giving a higher degree of choice to the transportation analyst and a higher utility of the available database (16-17).

PROBLEM FORMULATION

During the assessment of the scientific literature on TAZ definition, the existence of contradictory goals in the rules (i.e. contradictory goals of minimization of the statistical and the geographical errors) has been detected.

From this premise, a methodology of delineation of zones was defined, that tries to reduce the noise level (intra-zonal trips plus the number of non statistically significant trips of the O/D matrix) of the data for the traffic modeling, and at the same time minimizes the geographical error of the location of trips extremes.

The methodology intends to define zones (for a given range in their number) so that:

- Zone limits correspond to places with very low generation of trips (reducing ambiguity of allocation of trips to zones).
- Minimize intra-zonal trips.
- Avoid defining zones with very low number of trips (high statistical error) or very wide surface (high geographical error), except when far from the main problem area.
- Trip density inside a zone should be as homogeneous as possible.

It is important to notice that this methodology is mainly appropriate for macro transportation planning studies, where the used number of zones does not compromise the verification of the premises presented above (i.e. zones with continuous very low generation of trips). For the development of this methodology, the Lisbon Metropolitan Area (AML) was used as study area and its Mobility Survey the as database, since all the extreme points of the represented trips were geocoded.

METHODOLOGY OF ANALYSIS AND SELECTION OF ZONE LIMITS

The methodology for the determination of zones starts by the aggregation of the Mobility Survey trip extreme points into a grid cell. The grid cell into which the data is aggregated is variable, and depends of the size of study area and the precision intended for the study. For this analysis in the Lisbon Metropolitan Area a square cell grid with sides of 200 meters has been used.

For this process trip extremes were considered in an orographic (3D) view. The representation of the total number of trips starting or ending in each zone is made, considering that value as an altitude for each point. It is possible then, to determine the “orography” of the study area, considering a spline interpolation methodology for the points that do not have data available from the Mobility Survey sample.

This analysis was developed for the study area, but only considering Lisbon Municipality, due to the greater geographic precision in the location of the trip origins and destinations in the Mobility Survey available. The consideration of different geographic precisions in the location of extreme points of trips could bias the results of this analysis, due
to false concentration of trips in some specific points. The result of this analysis is presented in Figure 1, where it is possible to identify a higher concentration of origins/destinations of trips in Lisbon city center and near the Lisbon Municipality limits.

![FIGURE 1 Total origins and destinations in Lisbon Municipality 3D view.](image)

The TAZ Delineation Algorithm uses as background data the results of this orographic analysis, where each “mountain” is the “center” of a zone, which should be defined (limits) by the depressions surrounding it. The algorithm starts by the identification of the local “highest peaks” and their surrounding area, then sorts them decreasingly, and then uses a spreading geometric matrix for the design of the zones. The spreading geometric matrix is composed for each local “highest peak”, located in the center of the spreading matrix, allowing the formation of the zones, considering some spreading rules, in order to obtain homogeneous boundaries geometries for the zones. These rules were developed to avoid the delineation of zones with a very complex spatial structure, which could threat the applicability of the model in very complex urban areas, given its interpretation difficulties, even for experienced transportation analysts.

After this brief presentation of the methodological concept of the TAZ Delineation Algorithm, only the main features of the algorithm will be presented, as the space available in this paper does not allow a complete mathematical description.

The TAZ Delineation Algorithm is defined by five different constraints and an objective function with two variables. These constraints can be divided in two groups: the constraints derived from the algorithm goals (4 constraints) and the geographic constraint for the TAZ border delineation (avoiding overlapping between zones). The constraints derived from the algorithm goals are:

1. The total origins or destinations of trips in each TAZ should be greater than 70% of the average total origins or destination of trips (total origins or destinations of trips divided by the number of zones), which indirectly controls the statistical precision of the resulting zones.
2. Each TAZ area should be at least 70% of size of the surrounding areas of local “highest peaks” pre-defined which avoids the formation of zoning systems with a high heterogeneity of geographic precision.
3. The average statistical (relative) error in estimation of O/D matrix cells should be lower than 50%, which directly controls the statistical precision of each TAZ.
4. The number of zones should fall within the range previously defined by the analyst, which forces the algorithm to follow the analyst preferences.
These four constraints are the main algorithm constraints that are used from the beginning of its execution. The other constraint (geographic constraint) is only used when a TAZ has been already delineated, and forces TAZ limits to reach a frontier of an already formed TAZ (finding another boundary and stopping the search by defining the outer boundary of that specific zone), in order to obtain a zoning system that covers all the study area.

The first constraint is defined to control the establishment of zones with a very low and heterogeneous statistical precision, strongly correlated with number of trip origins or destinations of trips per zone. The second constraint was created to avoid the formation of very small zones, that could have a good geographic and statistical precision, but that led to a very heterogeneous geographic precision from a global point of view (very large zones to compensate other very small zones). These two indicators work as an indirect control over the statistical and geographic precision of the TAZ delineation.

The third constraint tries to directly limit the statistical precision in the estimation of the O/D matrix cells of each TAZ, controlling the average statistical error of each zone, assuming a distribution of trips of each TAZ as origin, by all TAZ’s, proportionally to the total flow in those zones as destinations. This constraint does not warrant that all the cells of the O/D matrix in which the zone is the origin are statistically significant, but considerably increases the likelihood that it so is.

The fourth constraint checks against a previously defined range of number of zones. This constraint is also one of the stopping criteria of the algorithm, which could not be satisfied if the given range of number of zones is too high for the available number of cells and data.

The geographic constraint avoids overlapping of the different zones and functions as limitation for the other constrains, because of the impossibility to reach some minimum constraint values with the aggregation of more cells.

The objective function of the TAZ algorithm contains two different variables: the variation of the density of trips and the percentage of intra-zonal trips of each zone (see Figure 2). This objective function tries, simultaneously, to optimize these variables by minimizing the variation of the density of trips (across cells inside each TAZ), arranging more homogeneous zones, and minimizing the percentage of intra-zonal trips of each zone (not a global minimization).

\[
\min_k \left( \frac{\text{Av} \cdot \frac{T_j}{A_j}}{\text{min D}} \right)
\]

\(\text{Av}\) - Average trip density in cell of TAZ
\(T_j\) - Origins + Destinations of trips per cell
\(A_j\) - Area of each cell
\(D_j\) - Total Intra-zonal trips per cell

**FIGURE 2 Decision tree to determine the optimum of the TAZ algorithm objective function.**
For the first variable minimization is done on the standard deviation of trip density across the cells of each TAZ, and for the second, on the sum of intra-zonal trips. These equations can have minimum values at different points, what is resolved by the use of a ranking function, which minimizes the sum of the rankings in the two variables (see Figure 2).

If the ranking function retrieves the same result for different cases, the objective function considers as the “most suitable” result the one that has the lower standard deviation of trip density. The decision tree used for the objective function is presented in Figure 2, where the three different evaluation steps of the objective function can be seen.

The algorithm needs the definition of some parameters, which are important for the establishment of constraints, as well as optimization of some additional features of the algorithm (ie. the optimal number of zones for a given range, which depends on some macroscopic indicators of the algorithm that will not be presented in this paper).

These parameters are:

- Definition of a main modeling area (core problem area) – compulsory input.
- Definition of an acceptable range for the number of zones (searching for the most favorable solution) – compulsory input.
- Size of the surrounding areas of local “highest peaks” for TAZ delineation.
- Percentage of zones belonging to the main modeling area.
- Typical Area proportion between zones in the main modeling area and the “rest of the world” zones area.
- Some parameters of the indicators (macroscopic indicators) used to define the optimal number of zones of the given range of number of zones.

Having the basic algorithm developed the assessment of the results led to the conclusion that some local improvements should be developed in order to verify some constraints to TAZ definition not considered in the basic algorithm. The main improvements identified were: a border conversion that would transform the irregular polygons borders of TAZ into administrative or statistical land units; a local statistical optimization of TAZ borders; a urban barriers correction that would adjust the TAZ borders to a previously identified group of urban barriers; and a major flow corridors correction that would adjust the TAZ borders to the main study area flow corridors. These improvements to the basic algorithm are not presented in this paper due to the space restrictions (18).

RESULTS FROM THE CASE STUDY

After an overview of the TAZ Delineation Algorithm methodology, the results of the application of this algorithm to the Lisbon Municipality are presented.

The analysis of results was focused in the measurement of the value-added introduced by the TAZ Delineation Algorithm. An example was developed to compare the evolution of several indicators with the different kinds of zoning systems (different methodologies and geometries). This example uses the same number of zones (53 zones like the number of boroughs (Freguesias) in Lisbon) for all methodologies in order to establish a direct comparison.
In this example we compare:

- The usual administrative units (with statistical information) quite often used as TAZ in traffic modeling in a municipality scale (these are the Freguesias ~ boroughs).
- A square cell grid leading to most favorable values of these indicators (1620 side square size and 20 degrees angle) (defined as Grid). This analysis can assessed in (18,19).
- The zoning system resulting from the TAZ Delineation Algorithm with regular geometry boundaries (defined as TAZ).
- The zoning system resulting from the TAZ Delineation Algorithm with irregular geometry boundaries “adjusted” to an aggregation of small scale statistical units (defined as TAZ BGRI ~ individual city blocks or a small group of them).

These different zoning systems are presented in Figure 3, where it is clear the difference between then, only the TAZ and TAZ BGRI zoning systems presenting some similarities (the TAZ BGRI zoning system was obtained from the former using a border adjustment algorithm of the initial results to the small scale statistical units and is not presented in this paper). The main difference between the zoning systems rests upon the greater homogeneity of the geographical and statistical precision of the last two zoning systems. This fact results from the constraints of the TAZ Delineation Algorithm.

The indicators measuring the statistical and geographical precision and the information loss generated by the intra-zonal trips of the resulting O/D matrix for each zoning system are:

- To measure the statistical precision in the estimation of O/D matrix cells for each zoning system, we adopted the percentage of trips in non statistically significant O/D matrix cells (defining as limit for statistical significance, a relative flow estimation error lower than 50%). This corresponds to the amount of “noise” generated by the Mobility Survey trips sample for the given zoning system.
- To measure the geographical precision of each zoning system we used the 75th percentile of the zone equivalent radius (in the subset of statistically significant zones, which are calculated through the TAZ average statistical (relative) error). This indicator retrieves a conservative value for the equivalent radius of a TAZ that is statistically significant, knowing that the larger a TAZ is, the bigger is the probability that a TAZ is statistically significant. This indicator provides very valuable information about the geographic precision of a zoning system (considering only the most “problematic” zones), giving a conservative estimation of the geographical error of the location of the extreme points of trips for the available zoning system.

\[
AVER_{STAT} = \frac{\sum_{i=1}^{N} \left( \frac{SWCI}{P} \right)^{j}}{N}
\]

\[
R_{E}(i) = \frac{\max_{N-U} \{R_{E}(j)\} - R_{E}(i)}{\max_{N-U} \{R_{E}(j)\} - \min_{N-U} \{R_{E}(j)\}} (m)
\]
\[
R_{E}^{(75\%)} = \text{Sort Ascending} \left( \text{if} \ (\text{AVER}_{\text{STAT}_{i}} \leq 0.5; R_{E_{i}}; 0) \right) \left( 0.75 \cdot (k + 1) \right)_{\text{RANKING ELEMENT}} \\
k = \sum_{i=1}^{N} \text{if} \ (\text{AVER}_{\text{STAT}_{i}} \leq 0.5; 1; 0)
\]

- To measure the information loss generated by the intra-zonal trips of the resulting O/D matrix for each zoning system we used the percentage of intra-zonal trips of the O/D matrix (resulting from the sum of the O/D matrix main diagonal cells). This corresponds to the percentage of the Mobility Survey trips that can not be assigned to the transportation network for the given zoning system.

FIGURE 3 Zoning systems compared in the Lisbon Municipality example.
These three indicators were calculated for the different zoning systems under analysis. The results are presented in Table 1, where it can be seen that the values obtained for the zoning system Freguesias are worse than those obtained by any other analyzed zoning system. This evidence might be justified by heterogeneity of size of zones for this zoning system, which presents very small zones in the Lisbon city center and very large zones near the Lisbon municipality borders. This fact can generate a high percentage of intra-zonal trips and low geographic precision in the large border zones, and at the same time, a high percentage of trips in non statistically significant O/D matrix cells, caused by the trips that have one of their extreme points in the very small zones of the Lisbon city center.

The Grid zoning system, formed by averagely larger zones, presents more homogeneous values along all the zones, leading to overall better results than the Freguesias zoning system (see Table 1). This fact reveals that the zoning system commonly used as in traffic modeling in a municipality scale (Freguesias) presents higher information loss than a much simpler square cell grid with large and regular boundary zones (Grid).

This information loss can be very costly and can lead to two different situations: the traffic modeling results using this zoning system can present a high level of uncertainty, which can lead to transportation planning decisions with higher level of uncertainty and risk; or the level of uncertainty of the results is so high that new information has to be added to the available Mobility Survey, in order to increase the sample and reduce the errors (severely increasing the costs). These results show that zoning is not a trivial matter given the significant consequences it may have for information loss, confirming the value-added of careful zoning.

The zoning system resulting from the TAZ Delineation Algorithm with regular geometry boundaries (TAZ), presents considerably better values of the indicators than the previous zoning systems (Freguesias and Grid, as presented in Table 1), except for the percentage of trips in non statistically significant O/D matrix cells indicator, where a slight higher value is obtained than for the Grid zoning system (see Table 1). This small increase can be justified by the absence of statistical precision in the TAZ Delineation Algorithm objective function. In spite of this fact, the TAZ zoning obtains a great reduction in the percentage of intra-zonal trips and maintains approximately the same statistical error than the square cell grid (with larger and uniform zones).

The last analyzed zoning system, resulting from the TAZ Delineation Algorithm with irregular geometry boundaries “adjusted” to an aggregation of small scale statistical units (TAZ BGRI), presents better indicators values than all the other zoning systems (see in Table 1). The improvement in the values of the indicators from TAZ zoning system is only obtained by the replacement of regular geometry boundaries by irregular geometry boundaries.

<table>
<thead>
<tr>
<th>Zoning System</th>
<th>Percentage of intra-zonal trips (%)</th>
<th>Percentage of trips in non statistically significant O/D matrix cells (%)</th>
<th>75th percentile of the zone equivalent radius (in the subset of statistically significant zones) (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freguesias</td>
<td>10.37</td>
<td>14.43</td>
<td>1091.42</td>
</tr>
<tr>
<td>Grid</td>
<td>9.73</td>
<td>11.66</td>
<td>913.99</td>
</tr>
<tr>
<td>TAZ</td>
<td>8.24</td>
<td>12.62</td>
<td>571.15</td>
</tr>
<tr>
<td>TAZ BGRI</td>
<td>8.15</td>
<td>11.35</td>
<td>459.07</td>
</tr>
</tbody>
</table>
Next, we show the evolution of the indicators relative to each of the zoning systems previously presented (Grid, TAZ and TAZ BGRI) along with the variation of the number of zones. In Figures 4 to 6 it is possible to see that TAZ BRI has overall better results than the Grid and TAZ zoning systems. The TAZ BRI always presents better results in all the indicators than the TAZ zoning system, reinforcing the assumption that a zoning system with irregular geometry boundaries should present better results than an equivalent zoning system with regular geometry boundaries.

It is important to notice that Grid zoning system for 40 zones presents lower values of statistical precision indicator (approximately 20% less than the TAZ BGRI and 28% less than the TAZ), due to the averagely larger zones than the other zoning systems, but at the same time this zoning system presents a significantly higher percentage of intra-zonal trips (approximately 40% more than the TAZ BGRI and 32% more than the TAZ) and also a higher 75th percentile of the zone equivalent radius (approximately 33% more than the TAZ BGRI and the TAZ), as presented in Figure 5 and Figure 6.
FIGURE 5 Evolution of 75th percentile of the zone equivalent radius indicator versus the percentage of trips in non statistically significant O/D matrix cells indicator with the number of zones of the zoning system variation.

FIGURE 6 Evolution of 75th percentile of the zone equivalent radius indicator, the percentage of trips in non statistically significant O/D matrix cells indicator with the number of zones of the zoning system variation.
CONCLUSIONS AND FUTURE DEVELOPMENTS

Most Transportation Planning studies put a lot of effort in data collection, estimation of parameters and sophistication of models, but zoning rarely merits similar attention, normally being done on top of administrative units or ‘by common-sense’, neglecting the effects of zoning over the available data and the study accuracy.

This project tries to depict the TAZ effects over Transportation Planning studies, showing that zoning is not a trivial matter given the significant consequences it may have for the generation of statistical and geographical errors in the study results, and presents a new methodology to define zones using an orographic approach to the problem, and some additional local optimizations to the results.

An algorithm has been developed and programmed, allowing easy and optimized delimitation of TAZ within a pre-defined range for the number of zones (TAZ Delineation Algorithm). This algorithm uses only as input a geocoded database of the trips extreme points, a spatial grid cell, the size of which depends on the size of the study area, and six different parameters, three of them used as constraints to the TAZ definition process and the others as weights of the attributes of a compensatory model used for determining the optimal number of zones within a range. The objective function of this algorithm maximizes the trip homogeneity within each zone and minimizes the percentage of intra-zonal for each TAZ.

Essays made over different equivalent zoning systems (same number of zones) with regular grids show that:

- Zoning with an optimized regular grid may bring better results than zoning based on administrative units.
- A considerable range of the errors obtained with regular grids indicates the value-added of careful zoning.
- The suggested indicators allow an easy measurement of these errors for any zoning scheme adopted.

An important step is needed for consolidation of this knowledge: test the validity of the results obtained with a different database. Due to the scarceness of geocoded Mobility Surveys in Portugal, it was not possible during the project duration to assess this method with other Mobility Surveys in order to validate the obtained results. The developed algorithms must be tested using other databases, national or international, in order to quantify the sensitiveness of the results to different travel patterns and land use distributions.

Three main directions are envisaged for the next steps of this research:

- Look at the consequence of these different zoning strategies on the traffic load estimates on roads of intermediate and lower hierarchy, especially after the implementation of all the local refinements to the basis algorithm.
- Investigate the consequences of these findings for the process of matrix estimation from traffic counts, being aware that the assignment of trip to a zone directly affects the TAZ definition process. For this reason studies based on traffic counts might have a simultaneous definition of the zoning system and the O/D matrix, and not as exogenous and pre-defined process. This iterative process until the convergence of the zoning systems and O/D matrix might have a similar structure to...
that of the k-clustering algorithms where the centroids of the clusters change position in each iteration.

- Economically quantify the gain of statistical precision and the reduction of the percentage of intra-zonal trips obtained by use of the algorithm. This significant decrease of information loss can lead to the use of smaller sampling rates in data collection (usually very expensive) or to a significant increase to the quality of the data used in the Transportation Planning studies, obtaining more robust results for the same input data and costs.

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