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New Transport Visual Mapping Method Combining Time, Cost and Sustainability Applied to the Barcelona Region

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Abstract

This article presents a new methodology (Visual Mapping Method of Transport: VMMT) in order to produce practical maps easy to understand for transport users. These maps would be really useful to identify what the most convenient combination of mode of transport to get from one point to another the fastest, cheapest or/and the most sustainable way. VMMT methodology applied in Barcelona region. By analysing the resulting maps and detecting the presence of non-uniformity in them, it will also be possible to identify the areas with the worst transport services or infrastructure. However, it should also be noted that by applying the VMMT, accessibility indexes are obtained; these are valid for comparing different areas with each other.

Subject Areas

Sociology

Keywords

Transport, New Visual Mapping Method, Time, Cost, Sustainability, Barcelona

1. Introduction and Study Objective

If we analyze people's daily lives, transport is one of the most important aspects, as their activities cannot be carried out without moving [1]. People choose one mode of transport or another depending on the purpose of their trip.

On the other hand, the availability of modes of transport to move from one point to another is different so people can choose one mode or other, or the combination of different modes of transport to move from one point to another in the city with their desire to complete their trip. That is, for each journey, people have the choice between different transport modes, each one having specific characteristics, advantages and disadvantages and costs [2].

Understanding travel behaviour and the reasons for choosing one mode of transport over another is complex. The quality of a transport system is covered by many factors. In the large volume of literature on mode choice, considerations relative to comfort and safety within the vehicle, the time taken to cover the routes, waiting time, cost of the travel mode and sustainability, among other factors, are shown to be the transport variables that users most valued [1] [3]-[10].

In this respect, there are many studies have been carried out on the quality of transport. However, we have not found any methodology that brings us to quality maps that are easy to understand for the transport user, which allows them to identify quickly the combination of transport that is convenient for them to go from one point to another. It is very difficult, with the information that exists today on the different panels of bus stops, trains, trams or any modes of public transport, to know or deduce the answer to these questions when choosing a mode of transport or a route. Therefore, this will be the objective of this study.

Due to the above, this study presents a methodology called "Visual Mapping Method of Transport" (VMMT) to obtain some maps with which the transport user identifies:

- What is the most convenient combination of modes of transport for a user to get from one point to another in the fastest way?
- What is the most convenient combination of modes of transport for a user to get from one point to another in the cheapest way?
- What is the most convenient combination of modes of transport for a user to get from one point to another in the most sustainable way?
- What is the most convenient combination of modes of transport for a user to get from one point to another in the fastest, cheapest and the most sustainable way?

Thus, the objective of this research is to propose a methodology VMMT to obtain visual maps with which to identify the fastest, cheapest and/or the most sustainable way to go from one point to another in a region. In order to carry out this investigation, a specific case has been analysed. The province of Barcelona and its capital, Barcelona, have been chosen for this purpose. Barcelona is a Spanish province located in the northeast of the country, in the autonomous community of Catalonia. It is bordered by the province of Tarragona in the southwest, the province of Lérida in the northwest, Gerona in the northeast and the Mediterranean Sea in the southeast (**Figure 1**).

This paper is structured as follows. Section 2 delves into material and method aspects, describing and justifying the steps to be followed for the application of

Figure 1. Location of province of Barcelona. Source: Barcelona City Council.

the methodology (VMMT). Section 3 presents the resulting qualitative analysis and visual maps, which offers the user useful information to choose the way of transporting, considering the time, cost, sustainability and the combination of the three variables. Section 4 concludes the research in this field.

2. Materials and Methods

The design, production and use of the maps, resulting from the VMMT methodology, as a form of communication constitutes four stages or sub-processes:

- Collect the data.
- Manipulate and generalise data to design and construct maps.
- Display the map.
- Interpreting the information.

The method presented in this study focuses on the first and second of these points, while the user of the map carries out the last two points.

In this section, a description and justification is given of the steps to be taken for the application of the methodology (VMMT).

Figure 2 presents in a very general way the steps of the VMMT methodology.

2.1. Zones or Strata and Selection of Representative Points

Selection of representative points of origin

Following the steps indicated in Figure 2, the origin region and the destination city must be chosen first. The province of Barcelona and its capital, Barcelona, have been chosen for this purpose.

In order to simplify the study, the province of Barcelona will be stratified into 25 different areas (A = 25). The main objective of this stratification—zonation—is the previous distribution of the whole sample to guarantee a minimum and homogeneous representation of each stratum and therefore of the trips it generates.

It is considered interesting to differentiate the most representative areas from these regions. The number of inhabitants of the towns/cities in each of the zones and the number of trips per hour to the destination zone have been considered.

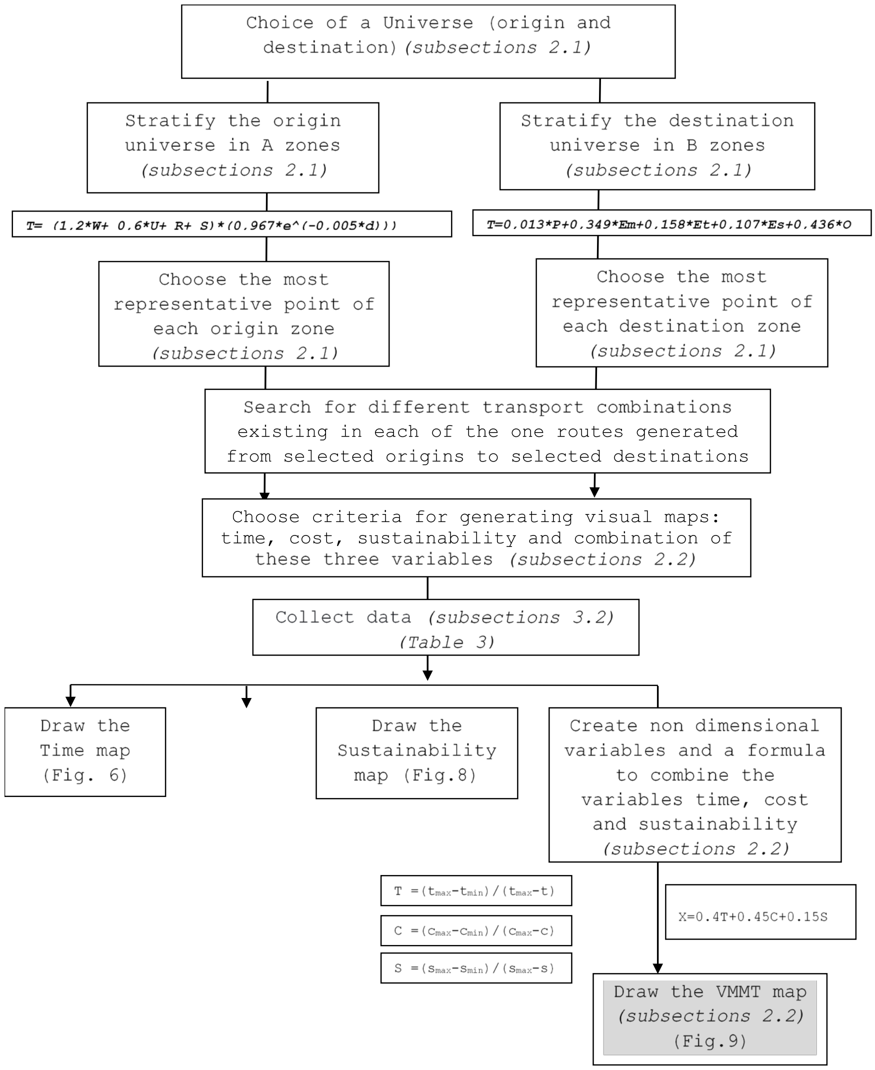

Figure 2. The VMMT methodology. Source: Author's own elaboration.

To calculate the number of trips produced, the equation based on a study carried out by the City Council of Barcelona [11] has been followed.

$$T = \left(1.2 * W + 0.6 * U + R + S\right) * \left(0.967 * e^{-0005 * d}\right)$$

Being:

T: Number of Trips;

W: Working Population;

U: Unemployed Population;

R: Retirees;

S: University Students;

d: Distance from the origin to the destionation (Km).

In this way, the 25 most representative points of the province of Barcelona are chosen as the origin.

Selection of representative points of destination

In order to choose the most representative destination points, the capital of

Barcelona is divided into 4 strata (B = 4).

In each zone, the number of inhabitants of the towns/cities and the point that attracts the most trips per hour has been chosen. For this calculation, the equation based on a study carried out by the City Council of Barcelona [11] has been followed:

$$T = 0.013 * P + 0.349 * Em + 0.158 * Et + 0.107 * Es + 0.436 * O$$

Being:

T: Number of trips;

Et: Retail trade employment;

P: Population;

Em: Employment of manufactures;

Es: Services (number of university students, number of teachers, employees in ambulatory clinics, employees in hospitals);

O: Other jobs (number of hotel and catering employees, number of employees in shopping centre).

In this way, the 4 most representative points of the capital of Barcelona are chosen as the destination.

2.2. Criteria for Evaluating Combinations of Modes of Transport

Once 25 representative origin points and 4 representative destination points had been selected, the different combinations existing in each of the one hundred routes generated were studied.

Once the different existing transport combinations from each origin to each destination were known, the time, costs and sustainability were calculated.

The following speeds have been used to calculate travel times based on studies by Emilio Ortega Pérez [12], see **Table 1**.

When calculating the costs of each of the modes of transport, the price of the actual ticket for each mode of public transport is noted, and in the case of transport by private vehicle, the price and consumption indicated in TRACCS is taken into account [13].

For the analysis of sustainability, the pollution produced by each of the transport combinations proposed will be studied, using the following emissions in grams of CO_2 per km **Table 2** [13].

Table 1. Speed per transport mode.

	Average city speed (km/h)	Average speed out of town (km/h)
Car	40	100
Bus	13.5	77.5
Train	120	120
Topo	80	80
Underground	80	80
Walking	5	5
Bike	15	15

Table 2. Grams of CO_2 per passenger and kilometre.

Transport mode	Car	Urban bus	Interurban bus	Underground	Train	Bike	Walking
Grams of CO_2 per passenger kilometer	104	68	68	14	38	0	0

Once the time, cost and sustainability have been calculated with the existing transport combinations from each origin to each destination, a formula is created that combines the three variables.

It does this by creating dimensionless variables of time (T), cost (C) and sustainability (S). A corrective coefficient is then applied taking into account the weight given to each of them according to a consultation in the work carried out by the City Council of Barcelona. The result shows that the cost is the most important (45%), followed by the time (40%) and last in order of importance is sustainability (15%).

Thus, the combination of the non-dimensional variables leads to:

$$X = 0.4T + 0.45C + 0.15S$$

where,

X: Global index of a combination of transport between the chosen origin and the chosen destination (between 0 and 1).

T: Non-dimensional time parameter of a combination of transport between the chosen origin and the chosen destination (between 0 and 1).

$$T = \left(t_{\max} - t_{\min}\right) / \left(t_{\max} - t\right)$$

t_{max}: The maximum time between all transport combinations of the chosen origin and the chosen destination.

t_{min}: The minimum time between all transport combinations of the chosen origin and the chosen destination.

t: The time of a combination of transport between a origin and destination.

C: Non-dimensional parameter of the cost of a combination of transport between the chosen origin and the chosen destination (between 0 and 1).

$$C = \left(c_{\max} - c_{\min}\right) / \left(c_{\max} - c\right)$$

c_{max}: The maximum cost between all transport combinations of the chosen origin and the chosen destination.

c_{min}: The minimum cost between all transport combinations of the chosen origin and the chosen destination.

c: The cost of a combination of transport between a origin and destination.

S: Non-dimensional sustainability parameter of a combination of transport between the chosen origin and the chosen destination (between 0 and 1).

$$S = \left(s_{\max} - s_{\min}\right) / \left(s_{\max} - s\right)$$

s_{max}: Grams of maximum CO_2 emissions between all transport combinations in the chosen origin and the chosen destination.

s_{min}: Minimum grams of CO_2 emissions between all transport combinations of the chosen origin and the chosen destination.

s: Grams of CO_2 emissions from a combination of transport between a origin and destination.

The closer X gets to 1, the better the transport communication will be.

2.3. Visual Maps

Once the origins and destinations have been chosen, the existing modes of transport between them are analyzed and a list is made of all the combinations that can be made.

With the aim of decide which is the best existing combination to go from one point to another, the time, costs, sustainability and the combination of the three variables of each alternative have been calculated and the results are represented through visual maps.

The time, cost, sustainability and the combination of the three variables (VMMT Application) of the chosen route are visually identified from the 25 origin points to the 4 destination points. Of all the combinations, the map of the best possible combination is presented.

3. Results

3.1. Zones or Strata and Selection of Representative Points

Selection of representative points of origin

As mentioned in the methodological part of the study to guarantee a minimum and homogeneous representation of the region the province of Barcelona will be stratified into different areas.

Figure 3 shows the province of Barcelona stratified into 25 zones.

The city of Barcelona is located in zone 3 of Figure 3.

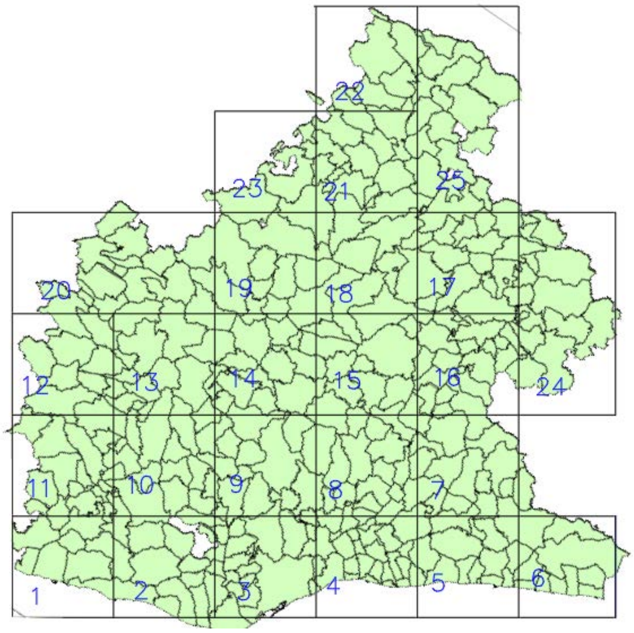

Figure 3. Province of Barcelona stratified into 25 zones. Source: Barcelona City Council.

The number of inhabitants of the towns/cities in each of the zones and the number of trips per hour to the destination zone have been considered.

In this way and using the formula that calculates the number of trips per hour produced from an origin to a destination, a representative point is chosen for each zone.

From each stratum, taking into account the number of inhabitants of the towns/cities, two are selected, taking as criteria those with the largest number of inhabitants. From the previous filter and considering the ones that generate the most trips, only one place from each stratum is selected. Thus, the most representative point of each area has been chosen, giving rise to 25 selected sites.

Thus, as representative points of each zone, the following have been selected:

Villanueva i geltru, San Baudilio de Llobregat, Cornellá de Llobregat, Badalona, Mataró, Pineda de Mar, Sant Celoni, Granollers, Sabadell, Viladecans, Villafranca del penedes, Santa Margarida de Montbui, Igualada, Manresa, Castellterçol, Vic, Sant Hipòlit de Voltregà, Sallent, Súria, Sant Martí Sesgueioles, Berga, Bagá, Montmajor, Torelló eta La pobla de Lillet.

Selection of representative points of destination

Figure 4 shows the location of Barcelona in Province of Barcelona.

Similarly, the city of Barcelona is divided into 4 zones as can be seen in Figure 5.

From each stratum, taking into account the number of inhabitants of the towns/cities, two are selected, taking as criteria those with the largest number of inhabitants. From the previous filter and considering the ones that attract the most trips per hour, only one place from each stratum is selected. Thus, the most representative point of each area has been chosen, giving rise to 4 selected sites.

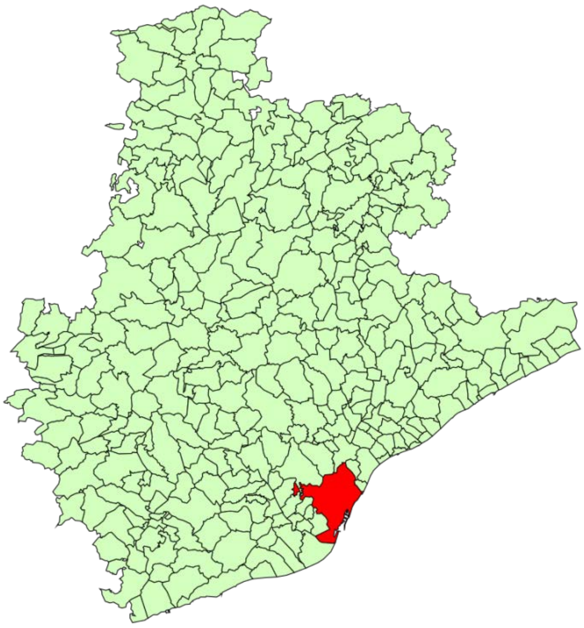

Figure 4. Location of Barcelona in province of Barcelona. Source: Barcelona City Council.

Figure 5. City of Barcelona stratified into 4 zones. Source: Barcelona City Council.

Thus, the following representative points are selected as the destination: Eixample, Sant Martí, Sarriá San Gerbasi and Sant Andreu.

3.2. Criteria for Evaluating Combinations of Modes of Transport

The next step is to make a list of the different modes of transport and their combinations that transfer users from each representative origin to each representative destination.

So that the calculations of time, cost and sustainability of each alternative are the same, a more specific point is chosen in each of the previously selected destination districts. The locations chosen from each of the most representative destinations are as follows:

Zone 1: Eixample—Plaça Espanya;

Zone 2: Sant Martí—Teatre Nacional de Catalunya;

Zone 3: Sarriá San Gerbasi—Plaça de Francesc Macià;

Zone 4: Sant Andreu—Plaça de la Republica.

The existing mode of transport is the following:

- Car;
- Bus (interurban or urban);
- Walking;
- Train;
- Bicycle;
- Metro;
- And the combination between each of one.

To better show how to use the methos, an example is included (Table 3). The

Table 3. Time, costs, sustainability and the combination of the three variables for each of the existing transport combinations.

ORIGIN: ZONE 1 VILLANUEVA I GELTRU
DESTINATION:ZONE 1 EIXAMPLE-PLAÇA ESPANYA
Distance 45.1 km

COMBINATION	TIME (min)	COST (€)	CONTAMINATION (gr CO_2/passenger)	T	C	S	X
Car	36	7	4690.4	1.0000	0.6215	0	0.6797
Walking + Busa (i)	67	14.88	3066.8	0	0	0.4000	0.0600
Walking + Train	50	2.2	1713.8	0.5484	1.0000	0.7333	0.7794
Bike + Train	40	2.25	1713.8	0.8710	0.9961	0.7333	0.9066
Walking + Underground	48	2.2	631.4	0.6129	1.0000	1.0000	0.8452
Bike + Underground	40	2.25	631.4	0.8710	0.9961	1.0000	0.9466

Source: Author's own elaboration.

following table list the data obtained for each of the existing combinations from Zone 1 to PLAÇA ESPANYA.

3.3. Visual Maps

Visual Maps: Time, Costs, Sustainability and VMMT Application

In the last step the results are represented through visual maps. The map offers the user useful information to choose the way of transport, considering the time, cost, sustainability and the combination of the three variables. Visual maps are effective modes of communication for the user.

The duration, cost and sustainability of the chosen route are visually identified from the 25 origin points to the 4 destination points by the maps. Of all the combinations, the map of the best possible combination can be presented. Following the example we will present the maps corresponding to Zone 1 to PLAÇA ESPANYA.

Visual Maps: Time

Figure 6 shows the best combination of mode of transport which corresponds to certain ranges of time (minutes).

Visual Maps: Costs

Figure 7 shows the best combination of mode of transport which corresponds to certain ranges of cost (€).

Visual Maps: Sustainability

Figure 8 shows the best combination of mode of transport which corresponds to certain ranges of sustainability. Pollution (g/traveller):

Visual Maps: VMMT Application

As a result of applying the VMMT method of transport service analysis in an area of influence, we produced the following map, which is really useful and easy to understand for the public or private transport user. These maps can be produced for all origins and destinations.

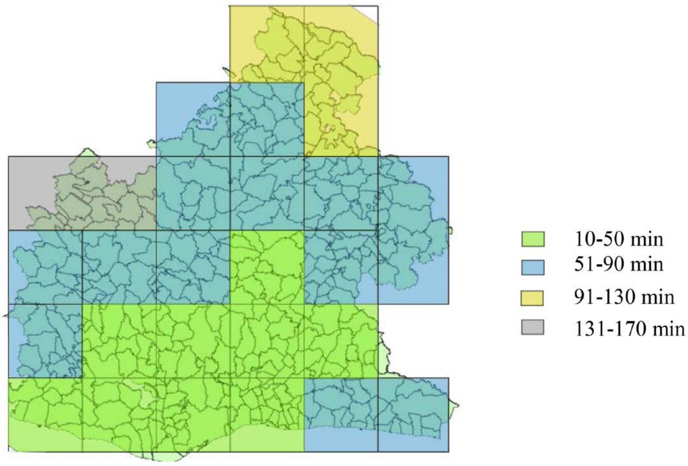

Figure 6. Visual map: Time. Destination: Zone 1; Eixample—Plaça Espanya. Source: Author's own elaboration.

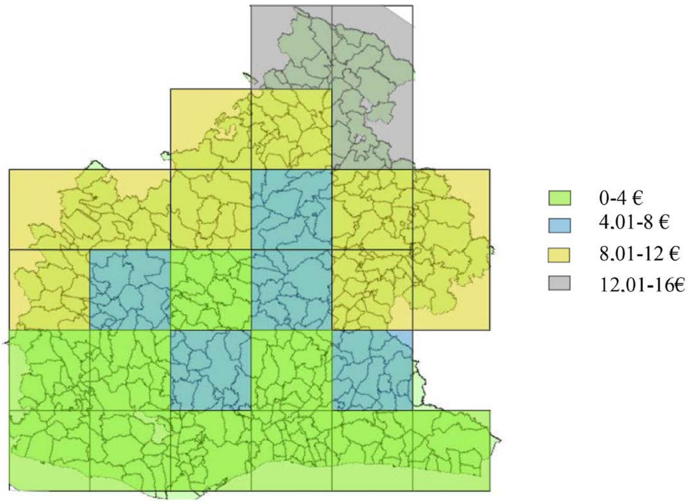

Figure 7. Visual map: Cost. Destination: Zone 1; Eixample—Plaça Espanya. Source: Author's own elaboration.

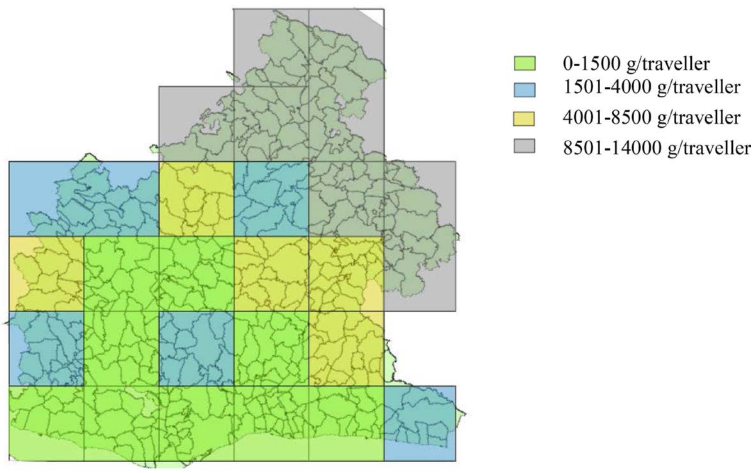

Figure 8. Visual Map: Sustainability. Destination: Zone 1; Eixample—Plaça Espanya. Source: Author's own elaboration.

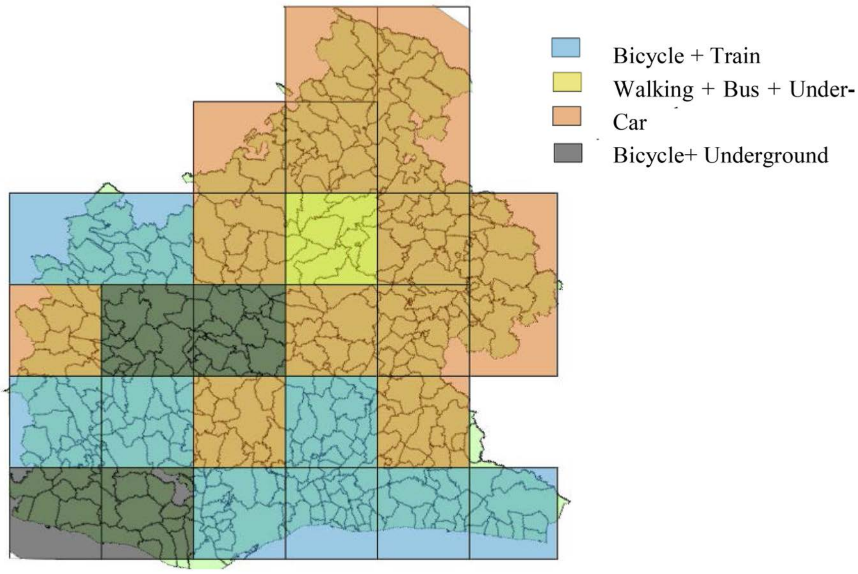

Figure 9. Visual Maps: VMMT Application. Destination: Zone 1; Eixample—Plaça Espanya. Source: Author's own elaboration.

Thanks to these visual maps, the user identifies which combination of transport is the most convenient to get from origin to destination.

Figure 9 shows the best combination of mode of transport which corresponds to certain ranges of time, cost and sustainability.

4. Conclusions

This paper offers a new point of view by introducing a new visualization mode of transport.

Whatever the quality of transport we have, we propose a methodology called Visual Mapping Method (VMMT) in order to be able to achieve a more global way of visualizing the total number of combinations offered by a region to public and private transport.

The existing visualisation types have been analysed. But none of them managed to reflect the basic points raised in this study. We have not found any visualization mode that gives us information about what is the most convenient combination of modes of transport for a user to get from one point to another in the fastest, cheapest or/and most sustainable way. That is, no visualisation has been found that combines all the types of transport that can pass through the origin of the route and that values not only the time and cost of these (variables previously analyzed by authors such as Vega *et al.* [14], but also analyses the sustainability of each of them.

By applying the methodology presented in this paper, an effective visualisation for the user is obtained, so that the map informs the user which combination of mode of transport will take him/her from one origin to a chosen destination in the fastest, cheapest and/or most sustainable way.

So, these maps are a new way of communicating information, the ideal way to transmit information visually. The advantage of this approach is its expressive power. The objective of designing these maps is to provide them with the capacity to transmit something more than what has been expressed so far in the information panels on modes of transport.

It is interesting to highlight the practicality of these maps, the result of the VMMT application, for transport users. Anyone moving from one point to another will be able to see at a glance which is the best option to reach their destination, taking into account time, cost, sustainability or the combination of the three variables mentioned.

The result of the application of the VMMT methodology to a region also provides a global and easy to interpret vision of accessibility. It is a very useful tool for the geographical planning of future infrastructures with the added value that this method also takes into account the sustainability of each mode of transport, a line reinforced in the article published by Bertolini *et al.* [15]. Other works have been carried out with the same objective of visualizing the accessibility of regions such as Johnston, R. A. *et al.* [16] among others, but they do not analyze the influence of sustainability.

It is worth noting the usefulness of the VMMT application for comparing different regions with each other through the resulting accessibility indices.

On the other hand, by analysing the resulting maps, it is possible to identify the areas with the worst transport and infrastructure services.

Finally, in order to extrapolate the VMMT methodology and be able to apply the method to another territorial area, it would be necessary to adjust the weights of the variables to that territory.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Madhuwanthi, R.A.M., Marasinghe, A., Rajapakse, R.P.C.J., Dharmawansa, A.D. and Nomura, S. (2016) Factors Influencing to Travel Behavior on Transport Mode Choice. *International Journal of Affective Engineering*, **15**, 63-72. https://doi.org/10.5057/ijae.IJAE-D-15-00044

[2] Beirão, G. and Sarsfield Cabral, J.A. (2007) Understanding Attitudes towards Public Transport and Private Car: A Qualitative Study. *Transport Policy*, **14**, 478-489. https://doi.org/10.1016/j.tranpol.2007.04.009

[3] dell'Olio, L., Ibeas, A. and Cecin, P. (2011) The Quality of Service Desired by Public Transport Users. *Transport Policy*, **18**, 217-227. https://doi.org/10.1016/j.tranpol.2010.08.005

[4] Zhao, F., Li, M.-T., Chow, L.-F., Gan, A. and Shen, L. (2002) FSUTMS Mode Choice Modeling: Factors Affecting Transit Use and Access. https://doi.org/10.5038/CUTR-NCTR-RR-2000-19

[5] Walter, C.K., *et al.* (1998) Multimodal Investment Analysis Methodology, Phase One: The Conceptual Model.

[6] Belgiawan, P., *et al.* (2014) Car Ownership Motivations among Undergraduate Stu-

dents in China, Indonesia, Japan, Lebanon, Netherlands, Taiwan, and USA. *Transportation* (*Amst*), **41**, 1227-1244. https://doi.org/10.1007/s11116-014-9548-z

[7] Tyrinopoulos, Y. and Antoniou, C. (2013) Factors Affecting Modal Choice in Urban Mobility. *European Transport Research Review*, **5**, 27-39. https://doi.org/10.1007/s12544-012-0088-3

[8] Sitlington, J. (1999) Moving to Healthier People and Healthier Places.

[9] Van, T., Choocharukul, K. and Fujii, S. (2014) The Effect of Attitudes toward Cars and Public Transportation on Behavioral Intention in Commuting Mode Choice—A Comparison across Six Asian Countries. *Transportation Research Part A*: *Policy and Practice*, **69**, 36-44. https://doi.org/10.1016/j.tra.2014.08.008

[10] Molinero, A. and Arellano, L.I.S. (1997) Transporte público: Planeación, diseño, operación y administración. Universidad Autónoma del Estado de México. https://books.google.co.ve/books?id=11R3sRgOZFAC

[11] De Barcelona, A. (2013) Pla de Mobilitat Urbana de Barcelona 2013-2018. http://w110.bcn.cat/portal/site/Mobilitat/menuitem.9a8066d1d6190a2591f791f7a2ef8a0c/?vgnextoid=560ace3a4c77b210VgnVCM10000074fea8c0RCRD&vgnextchannel=560ace3a4c77b210VgnVCM10000074fea8c0RCRD&lang=ES_ES

[12] Pérez, E.O., Quintana, S.M. and Pastor, I.O. (2011) Road and Railway Accessibility Atlas of Spain. *Journal of Maps*, **7**, 31-41. https://doi.org/10.4113/jom.2011.1167

[13] Papadimitriou, A., Ntziachristos, G., *et al*. (2013) Transport Data Collection Supporting the Quantitative Analysis of Measures Relating to Transport and Climate Change (TRACCS). Final Report Prepared for the Directorate-General for Climate Action, European Commission.

[14] Vega, A. and Reynolds-Feighan, A. (2008) Employment Sub-Centres and Travel-to-Work Mode Choice in the Dublin Region. *Urban Studies*, **45**, 1747-1768. https://doi.org/10.1177/0042098008093377

[15] Bertolini, L., Clercq, F. and Kapoen, L. (2005) Sustainable Accessibility: A Conceptual Framework to Integrate Transport and Land Use Plan-Making. Two Test-Applications in the Netherlands and a Reflection on the Way Forward. *Transport Policy*, **12**, 207-220. https://doi.org/10.1016/j.tranpol.2005.01.006

[16] Johnston, R. and de la Barra, T. (2000) Comprehensive Regional Modeling for Long-Range Planning: Linking Integrated Urban Models and Geographic Information Systems. *Transportation Research Part A*: *Policy and Practice*, **34**, 125-136. https://doi.org/10.1016/S0965-8564(98)00069-X