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EFFECTS OF BYPASS IN SMALL AND NON-CONGESTED CITIES: A CASE STUDY OF THE CITY OF BADAJOZ

ABSTRACT

Small cities with less than 200,000 inhabitants do not usually suffer from chronic congestion problems. However, private vehicles are used excessively, making it necessary to implement measures to encourage further use of public transport and pedestrian mobility to make it more sustainable. Bypasses improve level of service (LOS) by removing cars from the city center, leading to significant reductions in overall travel time. Most studies so far have been conducted in large cities suffering chronic congestion problems, so the aim of this research is to analyze the effects of bypasses in small and non-congested cities through the construction of a traffic model in Badajoz (Spain), starting with the allocation of the origin-destination travel matrix derived from surveys and traffic counts conducted at the southern and eastern accesses. The traffic model describes the mobility in potentially-capturable future southern traffic relationships and allows insights into different alternatives in the construction of a new high LOS road. This research concludes that small cities with no chronic congestion problems should plan bypasses as close as possible to the city, since they are the most economical, produce greater traffic capture, greater time savings, and eliminate the largest number of CO_2 emissions from the urban center. The more distant alternatives have a higher LOS, however, these are longer and more expensive solutions that also capture less traffic and thus eliminate less CO_2 emissions.

KEY WORDS

transport planning; traffic model; origin-destination matrix; Badajoz;

1. INTRODUCTION

Greenhouse gas (GHG) emissions and overconsumption of energy resources represent a global problem, which is related both to their causes and consequences [1].

The transportation sector is one of the largest emitters of GHG [2] despite advances in the field of engine technology. This sector accounted for 26% of global energy consumption in 2010, and transportation energy use is expected to increase by 1.1% every year until 2040 [3].

Small cities with less than 200,000 inhabitants do not usually suffer from chronic congestion problems. However, private vehicles are used excessively, making it necessary to implement measures to encourage further use of public transport and pedestrian mobility for greater sustainability. Bypasses improve LOS by removing cars from the city center, leading to significant reductions in overall travel time [4].

Evaluation of bypass influence on reducing air pollution has been carried out in numerous studies [5-7]. However, such studies are always carried out for large cities with congestion problems. It is therefore necessary to investigate whether such actions are also valid for smaller cities and to learn how to improve mobility and reduce emissions in urban centers [8, 9].

The city of Badajoz currently has a population of approximately 150,000 inhabitants. It is the main urban center in Extremadura, and it has the characteristics of any European average city. Moreover, its geographical location makes it even more privileged for being a border city and the barycenter of three huge European cities: Lisbon, Madrid, and Seville. [10]

The road network of Badajoz has a radial infrastructure composed by an ensemble of roads which leave the city and whose axes serve as support for its own growth. The main road (BA-20) passing through Badajoz registers about 132,000 trips daily. Here arises the need for building a new southern bypass, which would allow cars coming from other towns to link with the motorway Madrid-Badajoz and the rest of the communication roads without entering the city center of Badajoz. The so-called Southern Bypass (Ronda Sur) will become an authentic variant of roads which will receive the status of fast track and, together with the motorway of Extremadura, will surround the whole city center of Badajoz [11].
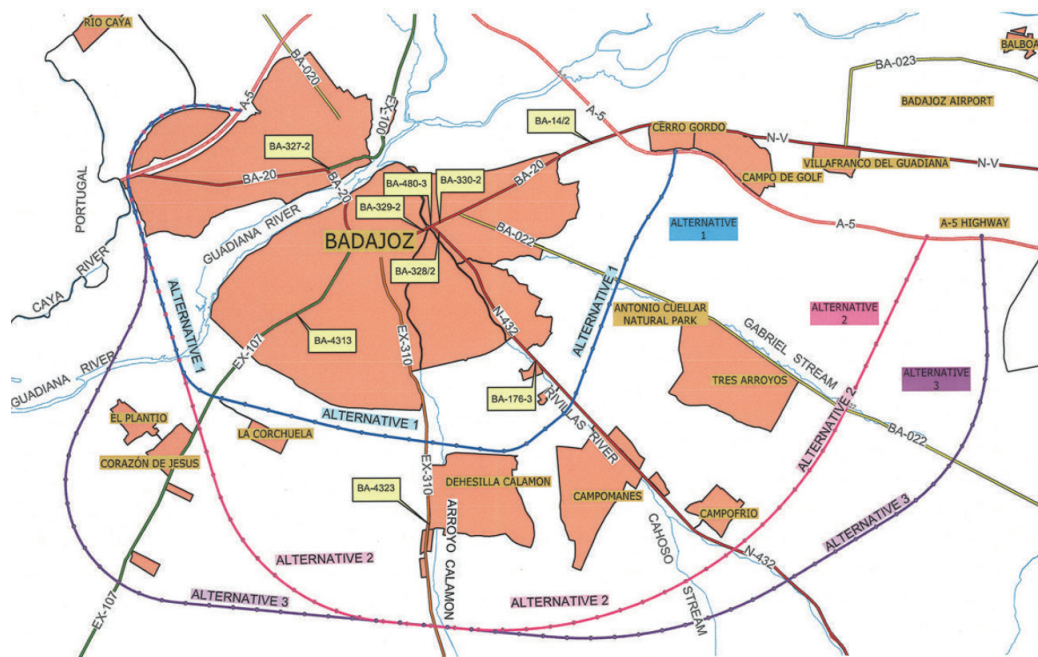
Figure 1 – Alternatives and counting stations studied at the Southern Bypass of Badajoz

Between 2010 and 2014 an informative study about the Southern Bypass in Badajoz was written, detailing its possible corridors and planning alternatives of the future variant [12] (*Figure 1*).

Alternative 1 is approximately 22 kilometers long. This alternative is the shortest and the closest to the city. It is also the one that was contemplated in the urban planning of Badajoz. Alternative 2 is approximately 30 kilometers long. It runs behind most of the secondary cores making the new route only pick up long distance traffic that does not need to cross the city. Alternative 3 has is approximately 36 kilometers long. It picks up some secondary cores that do not reach alternative 2, and it is outside the protected areas of oak forest that are occupied by this alternative.

On October 6, 2014, the Government of Extremadura approved the informative study [13] selecting the alternative 1. The three alternatives provide a solution to the problems of mobility and pollution existing in the urban center. The selected alternative is the most economical, since it is shorter; however, it is unknown if it is the alternative that captures more traffic and if it is the one that obtains greater savings in terms of travel times and CO_2 emissions.

The aim of this research is to analyze the effects of bypasses in small and non-congested cities by developing a traffic model for the city of Badajoz which provides insight into different alternatives' behavior in the construction of a new high LOS road. The model is able to select the one which captures more traffic and produces bigger savings in travel time and CO_2 emissions, meaning the one which produces better socio-economic improvement.

2. METHODOLOGY

Traffic study for the planning of new urban roads is an especially significant chapter, not only because it is necessary to know the number of vehicles that will circulate in each of the planned alternatives, but also as indispensable data to estimate their social and economic profitability [14]. It is very important to have the simulation model and allocation from the very beginning of the planning to have knowledge of the traffic that each of the corridors will capture, creating an extremely valuable auxiliary element for the selection process.

The construction of a traffic model in Badajoz will be done by assigning an origin-destination travel matrix derived from surveys and counts done at the southern and eastern accesses of Badajoz [15, 16]. The traffic model describes the mobility in potentially capturable relationships for a future southern bypass and allows the calculation of savings in traveled distance and travel times in relation to the current situation [17].

Activities done in the construction of the traffic model of the city of Badajoz are enumerated below:

1) Traffic characterization of the Southern Bypass of Badajoz starting from the data from the traffic maps of the Ministry of Development and Government of Extremadura [18, 19].

2) Collection and analysis of the information on mobility and traffic at the accesses to Badajoz from south and east, through surveys and counts.

3) Estimation of the average daily traffic (ADT) in specific count locations.

4) Utilization of the surveys carried out and collection of results.

5) Estimation of the origin-destination matrix in the studied area from the surveys done.

6) Creation of the traffic model of Badajoz and its road network.

7) Estimation of the traffic captured by each alternative selected for the Southern Bypass of Badajoz. This estimation derives from the assigning of the traveling matrix to each network, including the alternative which is the object of the evaluation.

8) Estimation of the traffic collected (vehicles-km) and travel time savings (vehicles-hour) for each selected alternative.

9) Estimation of CO_2 emissions saved from the urban center.

2.1 Collecting of information about mobility and traffic

Collection of information about transportation demand aims to determine how people move within the study area, in order to estimate mobility. The basic data collected for each trip will in this case be the means of transport, the origin of the trip, and its destination.

Willumsen [20] and, most recently, Bernardín et al. [21] recommend generating traffic models from surveys and counts *in situ* because they are not highly expensive and constitute the most truthful starting point there can be. Therefore, the basic form of collecting data has been through origin-destination surveys done in the city center of Badajoz. As a complement, information about network usage was collected through counts with the aim of learning how supply works, and giving information for the utilization of the surveys.

A total of 3,759 origin-destination surveys took place at the southern accesses of Badajoz which currently channel the potentially-capturable traffic for the future Southern Bypass.

Selection of locations for surveys and counts

Places with traffic lights were selected so that the survey could take place while every vehicle was stopped. After obtaining a view of the study area, five survey points were selected (*Figure 2*) and are listed as follows:

P1 EX-107. Avenue Luis Movilla Montero (Neighborhood of Llera).

P2 EX-310. Avenue Damián Téllez Lafuente crossing with BA-20.

P3 N-432 crossing with Avda. Luis de Góngora.

P4 BA-022 (Corte de Peleas road) crossing with BA-20.

P5 BA-20 (Avenue Juan Sebastián el Cano) crossing with BA-022.

Origin-destination surveys

3,759 surveys took place with the following distribution per survey positions:

Position 1	616 surveys
Position 2	604 surveys
Position 3	705 surveys
3.1. Straight movement	324 surveys
3.2. Turn in Luis de Góngora	381 surveys
Position 4	495 surveys
Position 5	634 surveys

The origin-destination surveys were taken on Wednesday, October 5, 2011, from 8 a.m. until 8 p.m., using the questionnaire in *Figure 3*.

Figure 2 – Survey points positions

TRAFFIC STUDY OF THE SOUTH BYPASS OF BADAJOZ
ORIGIN-DESTINATION SURVEY

Figure 3 – Survey template used [22]

Table 1 – Result of the vehicle count in the selected control locations

Vehicle count for the traffic study of the Southern Bypass of Badajoz						
	Luis Movilla Montero Avenue	Damián Téllez Lafuente Avenue	Sevilla Road N-432		Corte de Peleas Road	BA-20 J.S. El Cano
Time frame	Position 1	Position 2	Position 3.1 (Straight)	Position 3.2 (L. Góngora)	Position 4	Position 5
06:01 a 07:00	148	161	50	19	52	83
07:01 a 08:00	516	579	204	145	268	553
08:01 a 09:00	746	770	320	228	397	950
09:01 a 10:00	517	558	285	217	296	836
10:01 a 11:00	464	484	292	186	260	782
11:01 a 12:00	545	585	283	192	295	768
12:01 a 13:00	810	623	303	222	232	753
13:01 a 14:00	841	809	348	215	314	874
14:01 a 15:00	428	642	190	165	251	984
15:01 a 16:00	608	574	217	142	200	852
16:01 a 17:00	628	544	295	190	236	729
17:01 a 18:00	656	758	300	280	294	740
18:01 a. 19:00	686	642	267	178	362	908
19:01 a 20:00	749	663	351	249	387	1,103
20:01 a 21:00	963	673	329	235	321	933
21:01 a 22:00	951	518	205	115	147	524
Total vehicles counted	10,256	9,583	4,239	2,978	4,312	12,372

Counts

Simultaneously with the surveys, a 16-hour vehicle count (from 6:00 to 22:00) of the surveyed traffic was carried out. The results of the vehicle count are shown in *Table 1*.

2.2 Utilization of the surveys

The basic aim of the surveys was to obtain the expressive mobility matrix of the transport demand between each pair of zones considered. In survey utilization, three basic activities can be pointed out:

- Coding of surveys. It consists on translating numeric data and collected information in the survey, the origin-destination coding being of particular interest because it supports the division of the studied area into zones and the defined area codes [23, 24].
- Calculation of the expansion coefficients. It is about establishing the necessary conversion coefficient to extrapolate the results of the surveys from a part of the vehicles and users (sample) to the total of vehicles and users (universe).
- Collecting of the origin-destination matrix. After coding the surveys, the result is the origin-destination travel matrix which expresses the mobility flow of vehicles classified by type of vehicle and it refers to the universe of vehicles passing through the positions of the survey.

Calculation of the expansion coefficient

Expansion coefficient represents the converting coefficient from the surveyed users (sample) to the total of users (universe) [25]. This expansion coefficient has been calculated for each position of the survey and hour period through the following *Equation 1*.

$$EC_{i,h} = \frac{VC_{i,h}}{VS_{i,h}} \qquad (1)$$

where: $EC_{i,h}$ is the expansion coefficient of the surveys in position i during time period h; $VC_{i,h}$ are the vehicles counted in position i during time period h; $VS_{i,h}$ are the vehicles surveyed in position i during time period h.

The resulting expansion coefficients in survey positions are:

Position 1   1.2594
Position 2   1.0996
Position 3.1.   1.1437
Position 3.2.   1.1254
Position 4   1.1161
Position 5   1.2025

Construction of the origin-destination travel matrix in the study area for 2014

The origin-destination travel matrix was obtained through the following process:

1) Travel matrix expansion from the surveys to 2014 ADT estimated. Expansion coefficients described previously were used.
2) Matrices correction, checking each origin-destination relationship, and adapting the origin and/or destination zones to the survey positions.
3) Travel matrix in the study area captured in a single direction in the positions of the survey.
4) Duplication of the connecting trips in the western area of study captured in a single direction in the survey positions.
5) Travel matrix rezoning, making it a simplified 78 zone area. The selected zones for this simplification were: Zones 1 to 65 – considered for this count in the municipality of Badajoz, Zones 66 and 67 – Talavera La Real, Zones 68 to 78 – different accesses to the city of Badajoz.

3. RESULTS

3.1 Traffic model in the road network of Badajoz

Network assigning models simulate the behavior of a transportation network through the collecting of the traffic loads derived from the travel matrix. This matrix represents the mobility in the study area for a determined year. The traffic which the Southern Bypass will capture is obtained by assigning the 2014 travel matrix to the defined road network, including the 3 bypass alternatives for the future situation.

To be able to make a model of the network, a drawing which guaranteed all the possible coherent itineraries between each pair of centroids (representation of the origin and destination network of a journey) was made [26]. The road network of the study area for 2014 was modeled defining the following parameters for each route: origin knot, destination knot, distance between knots, type of arc, average travel distances, and circulation directions.

8 types of arcs and the following average travel velocities were considered: (1) roads in the city center (15-20 km/h), (2) roads in the surroundings (20-35 km/h), (3) urban motorway (60-80 km/h), (4) suburban motorway (100-110 km/h), (5) urban road (40-50 km/h), (6) suburban road (50-75 km/h), (7) centroid access (15 km/h), (8) bypass (80 km/h).

Cascetta and Ruso [27], and later Russo and Vitetta [28] and Shrewsbury [29], expressed the necessity of adjusting the network (calibration) by checking that the itineraries which allow establishing the modeled network correspond with the reality. This calibration is made calculating the minimum-cost paths (time and distance) from a group of selected centroids and checking them against the real ones used by the users in 2014.

Once it was modeled for the year 2014, the future model was made with the commissioning of the Southern Bypass. It was necessary to include the new arcs which describe each of its 3 alternatives. In *Figure 4* there is a representation of the road network in 2014, and in *Figure 5* there is a representation of the future network with the commissioning of the Southern Bypass.

3.2 Traffic captured by Southern Bypass alternatives

The traffic captured by each of the Southern Bypass alternatives was estimated by assigning the origin-destination travel matrix to the future route network which
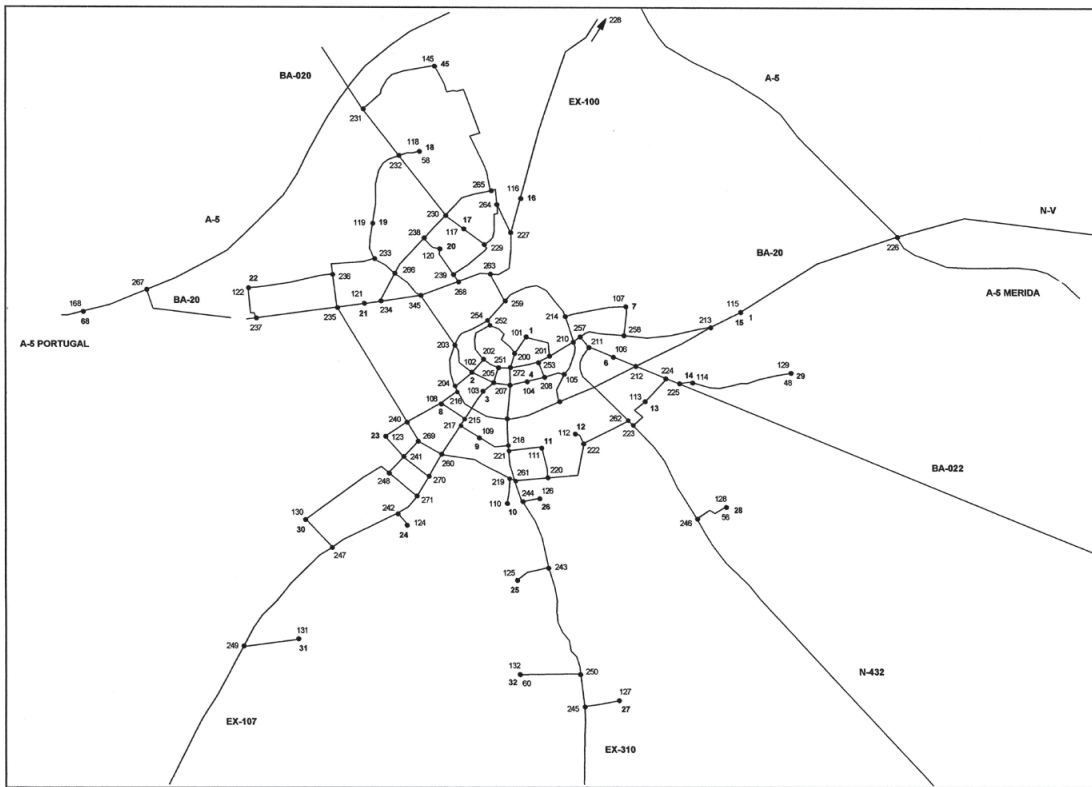
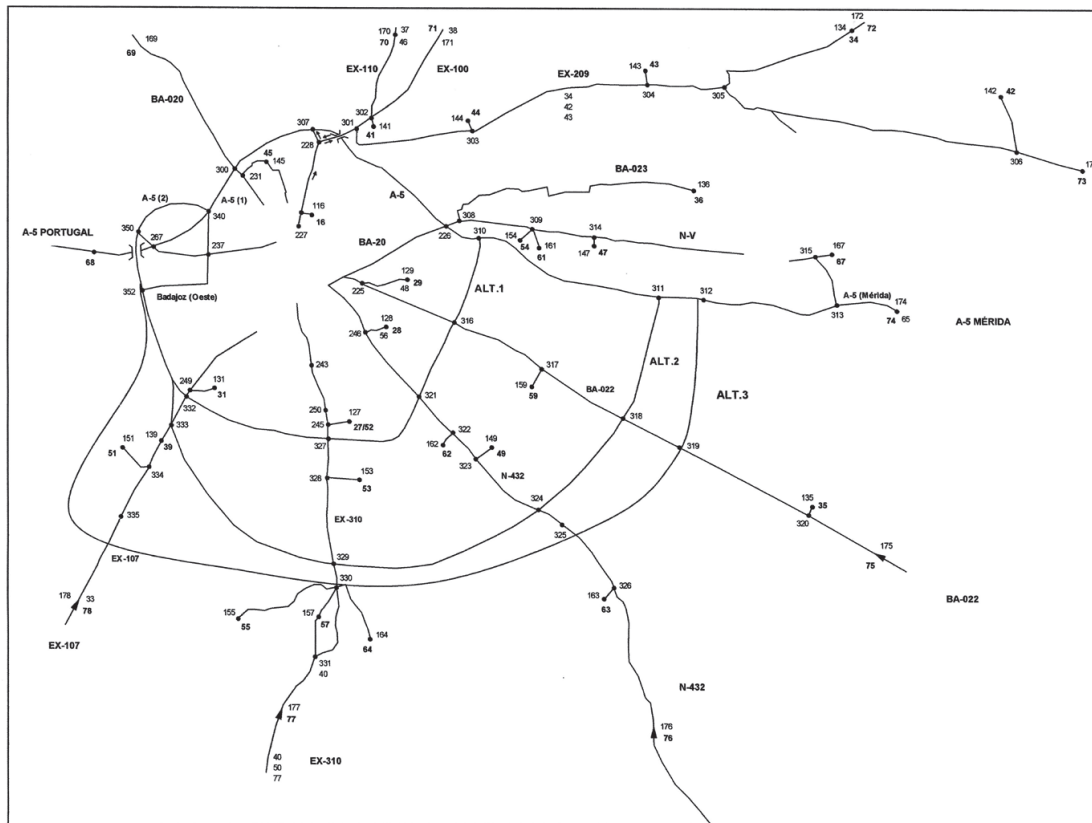Figure 4 – Traffic model of Badajoz city for the year 2014 [veh/h]

Figure 5 – Traffic model in Badajoz city with the commissioning of Southern Bypass [veh/h]

includes each of the 3 Southern Bypass alternatives. There are several methods to assign this, such as the "all or nothing" or the stochastic method. The stochastic methods of traffic assignment reveal the variability of the users, their perception of the costs, and the way to simultaneously minimize the distance and the travel time, therefore, the general costs. These methods could be based on a simulation as in Burrell [30], or they could be proportional. The proportional methods are based on a network load algorithm and distribute the trips which arrive to the node among the other entire possible exit knots, contrary to the "all or nothing" assigning method, which assigns all trips to an individual exit node.

In this research, the traffic assigning was carried out using a stochastic proportional method of assigning alternative routes: the Dial method [31]. In this method, two or more alternative routes are assigned between each pair of zones, dividing the existing flow between those itineraries, considering the generalized minimum cost (distance+time) and the generalized cost for each of the itineraries. According to the Dial method, the trips in each origin-destination relationship are divided among the different itineraries through a logit type division model. In *Equation 2*, the simplest case of a logit model is represented, which is the one that only considers two different options to choose from, considering for each trip the characteristics of the generalized cost. In this case, a similar one to the Ortuzar model is used [32] with the same primary and secondary modal split dispersion parameters ($\lambda_1=\lambda_2$), which makes it a simple multinomial logit model (MNL) [33, 34].

$$p(1) = \frac{1}{1 + e^{-\lambda(C_1 - C_2)}} \tag{2}$$

where: $p(1)$ is the probability of the traveler using itinerary number 1; C_1 and C_2 are the generalized costs of itinerary numbers 1 and 2, respectively; λ is the

dispersion parameter. Measuring the model from the known values through the surveys and counts, the value of $\lambda=0.10$ has been adjusted.

$C_1-C_2=0$ indicates that the utility of both options is the same, and the election probability of option 1 is 0.5, which corresponds to the situation of indifference against option 2. When the difference C_1-C_2 acquires increasing positive values, the utility of option 1 increases even more compared to the growth of option 2, and the probability of choosing option 1 tends to unity. When the difference C_1-C_2 acquires negative values indicating option 2 has better utility than number 1, the probability of choosing option 1 decreases, getting close to zero. The results of these estimations are presented for each of the Badajoz Southern Bypass alternatives in *Table 2*.

3.3 Traffic collected and travel time saving

During the process of assigning, the numbers of vehicles per kilometer (traffic) and vehicles per hour (travel time) used for the movements through the three Southern Bypass alternatives included in the travel matrix were obtained as complementary information. The difference in traffic captured and time saving is obtained when comparing the parameters of each alternative with those from the network in 2014.

It is important to highlight that the socio-economically most feasible alternative will be the one which obtains the highest number of vehicles-km and the least vehicles-hour, since it will be the one that captures more traffic and produces greater time savings. The results are presented in *Table 3*.

Alternative 1 is the one that collects the most traffic (2.25% more than in 2014); it is also the one that saves more travel time, reducing the situation of 2014 by 1.82%.

Table 2 – Number of vehicles per hour captured by the Southern Bypass alternatives

Alternative 1									
A-5/ PORTUGAL	928	EX-107	2,163	EX-310	5,336	N-432	2,094	BA-903	2,166	A-5/ MÉRIDA
Alternative 2									
A-5/ PORTUGAL	843	EX-107	1,137	EX-310	1,803	N-432	732	BA-903	813	A-5/ MÉRIDA
Alternative 3									
A-5/ PORTUGAL	463	EX-107	601	EX-310	1,568	N-432	701	BA-903	772	A-5/ MÉRIDA

Table 3 – Differences in vehicles-km (traffic) and vehicles-hour (travel time) between each Southern Bypass alternative and comparison with the network in 2014

Parameters	Year 2014	ALT-1			ALT-2			ALT-3		
		Value	Dif.	%	Value	Dif.	%	Value	Dif.	%
Vehicle-km	550,926	563,244	+12,418	+2.25	557,395	+6,470	+1.16	554,147	+3,221	+0.58
Vehicle-h	11,226	11,022	- 204	-1.82	11,141	- 85	-0.76	11,134	- 92	+0.82

3.4 CO₂ emissions

The measurements were made with vehicles of different typology (Fiat 500 1,200 cc gasoline and Opel Astra 1,600 cc diesel) to analyze the difference of impacts between types and to be able to apply them to the fleet of the city of Badajoz (*Table 4*). The results are shown in *Table 5*.

Alternative 1 is the one that captures more traffic and therefore eliminates the largest number of vehicles from the city center and the highest amount of CO_2 emissions.

4. CONCLUSIONS AND DISCUSSION

Planning new high-capacity roads in small cities, whether they are collective-distributor routes or single variants, requires an effective traffic model which is able to provide insight into the mobility of the current city and simulate the future behavior with the commissioning of the new route. Designing an adequate traffic model provides information about the behavior of different potential alternatives in the construction of a new high-capacity route, and, in this way, facilitates selecting the one which captures more traffic and produces bigger savings in travel times, meaning the highest socioeconomic feasibility.

This research analyzes the effects of bypasses in small and non-congested cities by developing a traffic model in Badajoz, starting from the assigning of the origin-destination travel matrix derived from the surveys and counts made at the southern and eastern accesses of Badajoz. The traffic model describes the mobility in potentially-capturable relationships for the

Table 4 – Technical information of the vehicles used in this research [35, 36]

Features	Astra values	Fiat values
Name	Opel Astra 1.6 CDTI 110 cv	Fiat 500 1.2 69 CV
Commercial section	Saloon	Minis
Engine type	Diesel	Gasoline
Cylinder capacity (cm^3)	1598	1242
Gear shift type	Manual	Manual
Maximum permitted mass	2010	1305
Power CV	110,05	93,75
Dimensions (WxDxH) [mm]	4419x1814x1510	3546x1627x1488
Maximum number of seats	5	4
Average fuel consumption	4,1	4,9
Emissions [gCO2/km]	109	115
Emissions [gCO2/l]	2,658	2,347
Classification by relative consumption	A ▸	D ▸

Table 5 – Vehicles and CO₂ emissions in the Southern Bypass alternatives saved from the urban center

Alternative 1						
	A-5/ PORTUGAL-EX-107	EX-310	N-432	BA-903	A-5/MERIDA	Total
Vehicles	928.0	2,163.0	5,336.0	2,094.0	2,166.0	12,687.0
Length [km]	8.3	4.6	3.5	2.6	3.0	22.0
Emissions [kgCO$_2$]	862.7	1,114.4	2,091.8	609.8	727.8	5,406.5
Alternative 2						
	A-5/ PORTUGAL-EX-107	EX-310	N-432	BA-903	A-5/MERIDA	Total
Vehicles	843.0	1,137.0	1,803.0	732.0	813.0	5,328.0
Length [km]	8.7	7.0	6.7	3.8	4.0	30.2
Emissions [kgCO$_2$]	821.5	891.5	1,353.0	311.6	364.3	3,741.9
Alternative 3						
	A-5/ PORTUGAL-EX-107	EX-310	N-432	BA-903	A-5/MERIDA	Total
Vehicles	463.0	601.0	1,568.0	701.0	772.0	4,105.0
Length [km]	12.5	6.7	7.6	4.4	4.8	36.0
Emissions [kgCO$_2$]	648.2	451.0	1,334.7	345.5	415.1	3,194.5

future southern variant and allows calculation of savings in travel distances and times in relation to the situation in 2014.

Analyzing the results in *Table 3*, one might conclude that, from the point of view of the traffic, alternative 1, which is the nearest to the city center, is preferred to alternatives 2 and 3 since it is the alternative with the highest number of vehicles-km (2.25% more traffic) and the one with the lowest number of vehicles-hour (1.82% less travel time). Alternative 1 is also the one that produces greater savings of CO_2 emissions from the city center (*Table 5*), reaching values that approximate 80% of the sum of the other two alternatives.

In terms of evaluating the performance of the method chosen, it is necessary to note that the "all or nothing" assigning methods and the stochastic methods do not take into account the capacities of the roads, assigning higher amounts of traffic to specific stretches which might not have that required capacity. The assigning method per stretches with capacity restriction takes this issue into account [37, 38]. However, due to the fact that Badajoz is not a city with severe traffic jam problems, the use of models which contemplate the restriction of capacity is not necessary, and the use of simpler methods which do not take this into account seems more adequate, such as the Dial method used in this research.

The chosen method should be used only in small cities which have no traffic jam problems. This is because in cities with traffic jam problems the application of the expansion coefficient constant to obtain the O/D matrix would produce a lot of errors [39, 40]. Moreover, as shown previously, there is the possibility of errors in traffic assignment considering the lack of capacity on the roads.

It is also necessary to emphasize that there are authors who use zoning-distributing models of gravitational demand, which are more economical since they do not require surveys and have proven to be sufficiently precise [41-45].

All these determinants make each assigning method suitable for a specific field of application in relation to the characteristics of the assigned network and the problem to analyze and evaluate. In interurban networks, the "all or nothing" and stochastic methods are usually used (Dial method). In urban networks, the capacity restricting methods per stretch are used and, to a lesser extent, the Burrel method. In interurban corridors, with alternative itineraries (toll motorway or important variants), the delivery curves are used [46, 47]. This method consists on supposing that between each pair of zones there are at least two alternative ways with their own characteristics of time, distance, and level of service. The journeys by the first or the second itinerary are distributed taking into account the already-established delivery curves, which define the percentage by either itinerary according to time

saved, distance saved, the travel time ratio, traveled distance ratio, etc. Due to the nature of the variant of the Badajoz Southern Bypass, it could be interesting as a future research detour to analyze an alternative model of assignment using this method and compare it to the results obtained in this research.

These results point to certain policy recommendations for small cities to develop bypasses as close as possible to the city, as it has been demonstrated in this research that it is the alternative that produces greater traffic capture, greater time savings and eliminates the largest number of CO_2 emissions from the urban center. It is also the alternative with the shortest route, therefore the most economical.

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EFECTOS DE BYPASS EN CIUDADES PEQUEÑAS Y NO CONGESTIONADAS: ESTUDIO DEL CASO DE LA CIUDAD DE BADAJOZ

RESUMEN

Las ciudades pequeñas con menos de 200,000 habitantes no suelen sufrir problemas crónicos de congestión. Sin embargo, el vehículo privado se usa excesivamente, por lo que es necesario implementar medidas para fomentar un mayor uso del transporte público y desplazamientos peatonales para hacerlo más sostenible. Los bypass mejoran el nivel de servicio (LOS) mediante la eliminación de los automóviles del centro de la ciudad, lo que lleva a reducciones significativas en el tiempo total de viaje. La mayoría de los estudios hasta ahora se han realizado en grandes ciudades con problemas crónicos de congestión, por lo que el objetivo de esta investigación es analizar los efectos de los bypass en ciudades pequeñas y no congestionadas a través de la construcción de un modelo de tráfico en Badajoz (España) comenzando con la asignación de la matriz de viajes de origen-destino derivada de las encuestas y recuentos de tráfico realizados en los accesos sur y este. El modelo de tráfico describe la movilidad en futuras relaciones de tráfico en el sur potencialmente capturables y permite conocer diferentes comportamientos alternativos en la construcción de una nueva carretera de alta LOS. Esta investigación concluye que las ciudades pequeñas sin problemas de congestión

crónica deben planear desvíos lo más cerca posible de la ciudad, ya que son los más económicos, producen mayor captura de tráfico, mayor ahorro de tiempo y eliminan la mayor cantidad de emisiones de CO$_2$ del centro urbano. Las alternativas más lejanas tienen un LOS más alto, sin embargo, estas son soluciones más largas y más caras, capturan menos tráfico y eliminan menos emisiones de CO$_2$.

PALABRAS CLAVE

planificación del transporte; modelos de tráfico; matrices origen-destino; Badajoz;

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