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Transportation Research Procedia 14 (2016) 3209 – 3217

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

TRA TRANSPORT RESEARCH ARENA

Obtaining a maximum AADT sustained by two-lane roads: an application to the Madrid region in Spain

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Abstract

At the time of developing the latest Road Master Plan for the Madrid Region (Spain), the question came up as to what traffic volume should be established as a criterion to trigger the upgrade of a two-lane highway to a four-lane facility. Conventional wisdom suggested a maximum annual average daily traffic (AADT) of 10,000 veh/day. The main objective of this research was to determine whether 10,000 veh/day is a reasonable upgrade threshold or if this threshold is too conservative and a higher value can be adopted. Assessment was made based on actual traffic volume measured in two-lane facilities, service vehicle tables provided by different highway agencies and a statistical analysis of the traffic volume distribution of in-service facilities in the Madrid Region. A total of 36 segments exceeding an AADT of 10,000 veh/day at some point between 1998 and 2008 were found and analyzed. Results indicated that maximum observed values fit fairly well with the service volume tables provided by HCM 2010 and FDOT and an increase in the upgrade threshold is feasible. These results offer guidance as to what value can be considered for future planning applications, including impact traffic studies and local and regional planning.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: Capacity; AADT; two-lane highway; planning; service volume table; level of service

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Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.263

1. Introduction

At the time of developing the latest Road Master Plan for the Madrid Region, the question came up as to what traffic volume should be established as a criterion to upgrade a two-lane highway to a four-lane facility. It was unclear whether a threshold should be based on capacity, level of service (LOS), or some other source. Conventional wisdom suggested that the maximum annual average daily traffic (AADT) for a two-lane highway was 10,000 veh/day. However, AADT values over 10,000 veh/day have been found not only in the Madrid Region, but also in many other two-lane facilities across the world.

Therefore, the main objective of this research was to determine whether 10,000 veh/day is a reasonable threshold for two-lane facility upgrade or if this threshold is too conservative and a higher value can be adopted. Assessment was made based on actual traffic volume measured in two-lane facilities, service vehicle tables provided by different highway agencies and a statistical analysis of the traffic volume distribution of in-service facilities in the Madrid Region. From a highway agency point of view, the need for funding is intimately tied to the traffic volume selected as threshold (the lower the threshold, the greater the funds required for upgrading the road network).

2. Literature review

Many professionals involved with transportation planning have a threshold of 10,000 veh/day as the maximum volume that should be handled by a two-lane highway. However, this conventional wisdom may not necessarily agree with traffic volumes observed in many two-lane facilities (Gehr et al., 2010). A good example of this is the N-370 east-west state highway in Nebraska. The Nebraska Department of Roads (NDOR) annually produces the “State Highway Needs Assessment”, as directed by the Nebraska Legislature (NDOR, 2014). This report establishes criteria for assessing the needs of the state highway system. According to this report, any facility experiencing a 20-year projected AADT greater than 10,000 veh/day warrants a four-lane highway. In addition, the Nebraska State Highway System Standards (NDOR, 2010) command a special study to determine the need for upgrade in two-lane arterial and collector facilities with an AADT over 9,000 veh/day. The 2010 traffic volume for N-370 highway near Gretna was 14,086 veh/day (LOS D), which clearly exceeded both thresholds. Evidence of two-lane traffic volume exceeding 10,000 veh/day is not unique of the State of Nebraska. AADTs over 20,000 veh/day have been reported in California, Pennsylvania, Washington as well as other countries (Torbic et al., 2009; Caltrans, 2014). In the case of Spain, maximum AADT values for two-lane rural facilities have been recorded in segments of N-340 highway near Villafranca del Penedes (26,000 veh/day), N-322 highway near Guardamar del Segura (25,000 veh/day) and N-II highway near Sils (22,000 veh/day) (Ministerio de Fomento, 2014).

From the standpoint of planning, Brilon and Weiser (1995) reported a diagram for the pre-selection of standard cross section based on AADT (Figure 1). Categories in Figure 1 are defined by a letter, which represents the environment (A = rural, B = urban), and a roman numeral, which refers to the functional classification (with I being major highways). Cross section type starts with the letters RQ, followed by road width expressed in meters. Thus, two-lane highways fall under the categories RQ 7.5, RQ 9.5 and RQ 10.5 (note that RQ 15.5 refers to a three-lane highway). The solid part of the bars in the figure indicates traffic volumes which always apply for the standard cross section under consideration. The shaded part covers AADT values where that particular cross section can be used under special external conditions. As can be observed in Figure 1, two-lane cross sections with 9.5 and 10.5 meters in width (RQ 9.5 and RQ 10.5) are considered valid up to 20,000 veh/day, which doubles the threshold suggested by conventional wisdom.

The Highway Capacity Manual (TRB, 2010) includes service volume tables to provide guidance on maximum traffic volume for a facility operating with a specific LOS. Table 1 exhibits the maximum daily volume that can be accommodated by a two-lane highway at a given LOS. Values presented in this table are a function of the planning analysis hour factor, K (ratio of traffic volume in the study hour to AADT) and the directional distribution factor, D. Table 1 shows that a threshold of 10,000 veh/day, which for most cases corresponds to a LOS D, may result excessively conservative to warrant conversion of a two-lane highway to a four-lane facility.

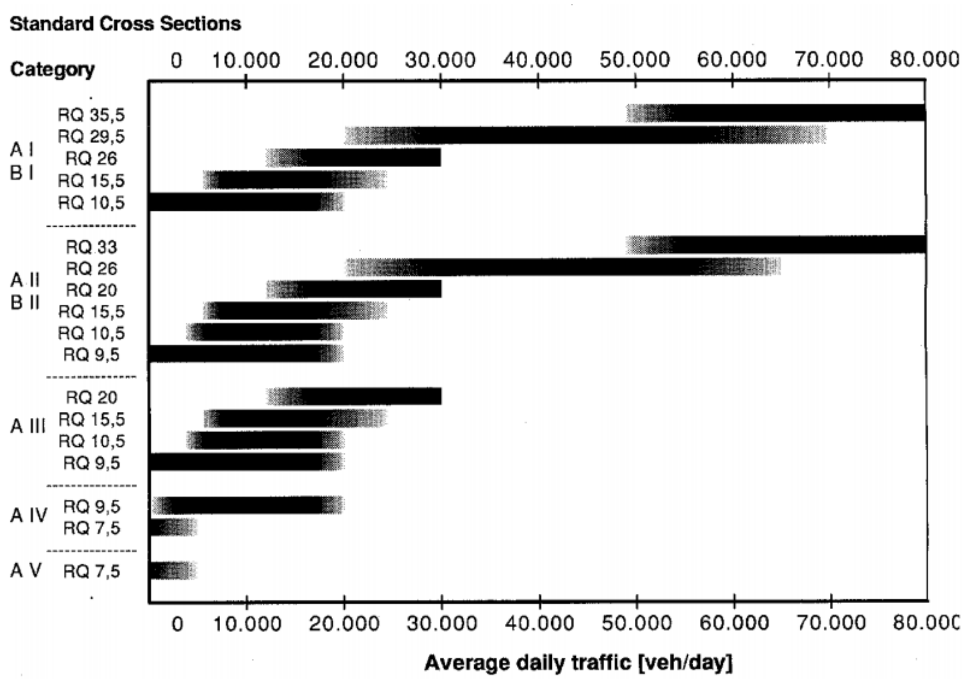

Fig. 1. Diagram for pre-selection of standard cross section based on AADT (Brilon and Weiser, 1995).

Table 1. Maximum daily volume (veh/day) accommodated by a two-lane highway (TRB, 2010).

K factor	D factor	Class I: Level terrain				Class I: Rolling terrain				Class II: Rolling terrain			
		LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E	LOS B	LOS C	LOS D	LOS E
9%	50%	5,500	9,300	16,500	31,200	4,200	8,400	15,700	30,300	5,000	9,800	18,200	31,200
	55%	4,900	8,700	14,900	30,200	3,700	7,900	14,000	29,200	4,100	8,700	16,000	30,200
	60%	4,400	8,100	13,900	27,600	3,700	6,200	12,800	26,800	3,700	7,900	14,600	27,600
	65%	4,100	7,900	12,900	25,500	3,400	5,900	11,400	24,700	3,300	5,900	13,200	25,500
10%	50%	5,000	8,400	14,800	28,000	3,800	7,600	14,200	27,200	4,400	8,800	16,300	28,000
	55%	4,400	7,900	13,400	27,100	3,300	7,100	12,600	26,300	3,700	7,900	14,400	27,100
	60%	4,000	7,300	12,500	24,900	3,300	5,600	11,500	24,100	3,300	7,100	13,100	24,900
	65%	3,700	7,100	11,600	23,000	3,000	5,300	10,300	22,300	3,000	5,300	11,900	23,000
12%	50%	4,100	7,000	12,400	23,400	3,100	6,300	11,800	22,700	3,700	7,400	13,600	23,400
	55%	3,700	6,500	11,200	22,600	2,800	5,900	10,500	21,900	3,100	6,500	12,000	22,600
	60%	3,300	6,100	10,400	20,700	2,700	4,700	9,600	20,100	2,700	5,900	10,900	20,700
	65%	3,100	5,900	9,600	19,100	2,500	4,400	8,500	18,500	2,400	4,400	9,900	19,100
14%	50%	3,500	6,000	10,600	20,000	2,700	5,400	10,100	19,400	3,200	6,300	11,700	20,000
	55%	3,100	5,600	9,600	19,400	2,400	5,100	9,000	18,800	2,600	5,600	10,300	19,400
	60%	2,800	5,200	8,900	17,700	2,300	4,000	8,200	17,200	2,300	5,100	9,400	17,700
	65%	2,600	5,100	8,200	16,400	2,100	3,800	7,300	15,900	2,100	3,800	8,500	16,400

Similarly, the Florida Department of Transportation (FDOT) publishes service volume tables with maximum AADT values by facility type for the purpose of planning analysis. Table 2 presents the values proposed for two-lane highways in the 2013 edition (FDOT, 2013). Although presented as daily volumes, they are based on peak hour directional conditions. In other words, peak hour directional values were divided by D and K factors to obtain daily traffic (values of D=55% and K=9% were assumed by the FDOT). Of note, LOS and capacity analysis make use of hourly volume; however, generalized planning does not require the same level of complexity and accuracy and it is more common to operate with daily traffic volume. As can be seen in Table 2, 10,000 veh/day, which would fall under LOS C, seems to be an extremely conservative value. It should be mentioned that the FDOT warns that generalized service volume tables should not be referred to as capacity tables. Roadway capacities for the day far exceed the volumes shown in daily tables because traffic is backed up for more than a 1-hour period.

Table 2. Maximum daily volume (veh/day) for two-lane facilities based on environment and level of service (LOS) (FDOT, 2013).

Environment	LOS B	LOS C	LOS D	LOS E
Urbanized areas	8,600	17,000	24,200	33,300
Areas transitioning into urbanized areas and areas over 5,000 population not in urbanized areas	9,200	17,300	24,400	33,300
Rural undeveloped areas and developed areas less than 5,000 population	8,700	16,400	23,100	31,500

Overall, values reported in the literature showed that a threshold of 10,000 veh/day is extremely conservative to trigger upgrade of a two-lane facility. As a reference, LOS D, which some highway agencies would argue as a reasonable threshold, could accommodate traffic volumes of up to 18,000-24,000 veh/day according to the service tables provided by the Highway Capacity Manual (HCM 2010) and the FDOT.

3. Study area

The Madrid Region comprises the city itself and the Madrid province, which has an area of approximately 8,000 km² (1.6% of all Spanish territory). The population of the city is roughly 3.2 million and the entire population of the region is a little over 6.3 million (as of January 2015). It is the third-most populous municipality in the European Union after Greater London and Berlin, and its metropolitan area is the third-most populous in the European Union after Paris and London.

There have been up to four Road Master Plans in the Madrid Region. In the advance of the first plan, the threshold established for two-lane highway upgrade was 10,000 veh/day. Subsequently, this value was set up as boundary between two-lane and multilane facilities in the first plan (1986-1993). The second plan (1994-2000) found that many two-lane roads operated with AADT values higher than 10,000 veh/day and the threshold was increased to 15,000 veh/day without further documentation. The next plan (2002-2009) defined the need for multilane highways for AADTs over 20,000 veh/day. The same plan stated that volumes between 10,000 and 20,000 veh/day could be served with either two-lane or four-lane facilities. In the latest plan, 10,000 veh/day is mentioned to establish priorities, but a threshold of 12,000 veh/day is defined to grant upgrading.

4. Selection of two-lane segments for analysis in the Madrid Region

Traffic counts provided by the Madrid Region highway agency were investigated for two-lane highways with AADTs over 10,000 veh/day for the 1998-2008 period (CAM, 1998-2008). A total of 36 segments exceeded this threshold at some point in this period. Among these 36 segments, seven were upgraded to four-lane facilities. Figure 2 shows the AADT in the 36 segments selected for this study (additional segment information can be found in Appendix A). For the seven segments that were upgraded, the last traffic volume as a two-lane highway was reported. For the other 29 segments, values in 2008 were reported for the sake of comparison. Note that the 2008 AADT in some segments was lower than 10,000 veh/day. This resulted from the traffic drop experienced due to the 2007 financial crisis.

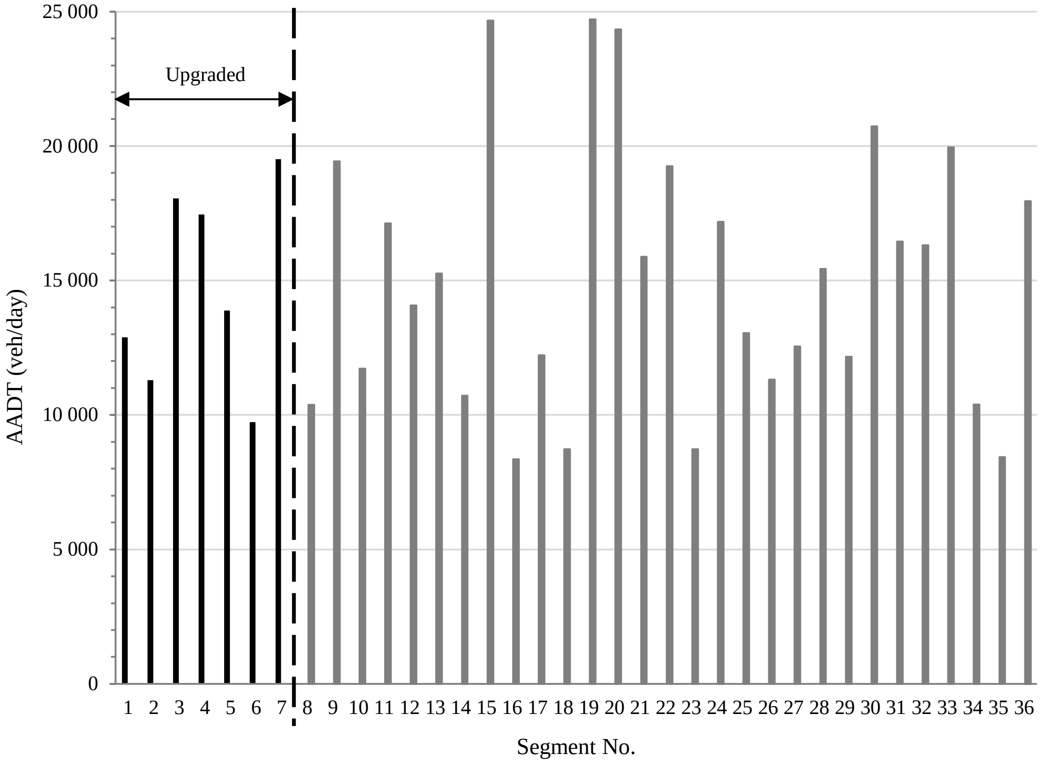

Fig. 2. AADT (veh/day) in two-lane highway segments selected in the Madrid Region. Segments 1 to 7 were upgraded to four-lane facilities and the last two-lane traffic volume is reported. For segments 8 to 36, traffic volume corresponds to 2008.

5. Results and discussion

A statistical analysis was conducted to examine the traffic volume distribution in the segments selected for this study. Table 3 summarizes the results for upgraded roads, two-lane roads and combined results. As can be seen, upgraded segments had an average two-lane AADT before conversion of 14,689 veh/day. In addition, the third quartile Q3 (75th percentile or the value exceeded by only 25% of the data) exceeds 17,700 veh/day. Note that only one segment had an AADT below 10,000 veh/day. Regarding two-lane segments that were not upgraded, an average AADT of approximately 15,000 veh/day was found. In this case Q3 reached almost 18,000 veh/day and only four out of 29 segments accommodated a volume below 10,000 veh/day. These results indicate that both upgraded and non-upgraded facilities presented similar distributions; i.e., no significant difference was found. Note that Q3, Q2, and even Q1 (25th percentile or the value exceeded by 75% of the data) are clearly above 10,000 veh/day.

Further comments on the results should be made with respect to capacity and comparison to values provided by service volume tables. First, there is always the legitimate question as to how much traffic volume is too much before undertaking an upgrading project. In this regard, traffic conditions approaching capacity were not observed and no user complaints were filed in any of the segments. It is noteworthy that values for capacity have grown with every new edition of the HCM from 2,000 veh/h to 3,200 veh/h in both directions, and 1,700 veh/h in the heaviest direction. In an unpublished study conducted by Nuñez and Romana in 2009, the heaviest 5-min traffic flow found in the Madrid Region was under 1700 veh/h. In fact, Elefteriadou et al. (2006) pointed out that capacity in two-lane highways is seldom reached and, thus, it does not seem an adequate criterion to establish an upgrade threshold.

Table 3. Results of statistical analysis on traffic volume distribution conducted on selected segments in the Madrid Region.

Descriptor	Upgraded	Two-lane 2008	All
Average (veh/day)	14,689	15,087	15,010
Std. error (veh/day)	1,400	909	773
Median (veh/day)	13,883	15,263	14,668
Std. deviation (veh/day)	3,703	4,894	4,641
Kurtosis	-1.735	-0.585	-0.507
Asymmetry	0.018	0.487	0.475
Range (veh/day)	9,780	16,349	16,349
Minimum (veh/day)	9,729	8,359	8,359
Maximum (veh/day)	19,509	24,708	24,708
Count	7	29	36
Quartile Q1 (veh/day)	12,092	11,311	11,306
Quartile Q2 (veh/day)	13,883	15,263	14,668
Quartile Q3 (veh/day)	17,758	17,958	17,983
IQ Range (veh/day)	5,667	6,647	6,677

Second, AADT values presented in this study can be compared to the guidelines proposed by Brilon and Weiser in Figure 1 for selection of cross sections. Although there is a general agreement, it should be noted that four segments exceeded the 20,000 veh/day limit recommended for two-lane highways by Brilon and Weiser. Comparison to values provided in service volume tables requires knowledge of the K factor. Table 4 and Figure 3 exhibit reference values commonly used in Spain. As can be seen, K values are approximately 8-10% for urban roads, 10-15% for rural roads and 15-20% for tourist roads. AADT values found in the Madrid Region agreed with those defined by HCM 2010 for Class I highway, LOS D, a K factor of 9-12% and a D factor of 50-60%. When compared to the FDOT service volume table, the vast majority of values fell under LOS C. In general terms, AADT values corresponding to LOS D as defined by the FDOT service volume table are uncommon in the Madrid Region.

Table 4. K factor for different facility types defined as the ratio of the traffic flow for the 100th heaviest hour (I_{100}) to AADT (Basque Regional Government, 1989).

Facility type	$K = I_{100}$ / AADT
Urban roads	8.0%
Local roads	9.5%
Intermediate length of trips	9.5%
Major intercity segments	10.5%
Tourist roads	15-20%

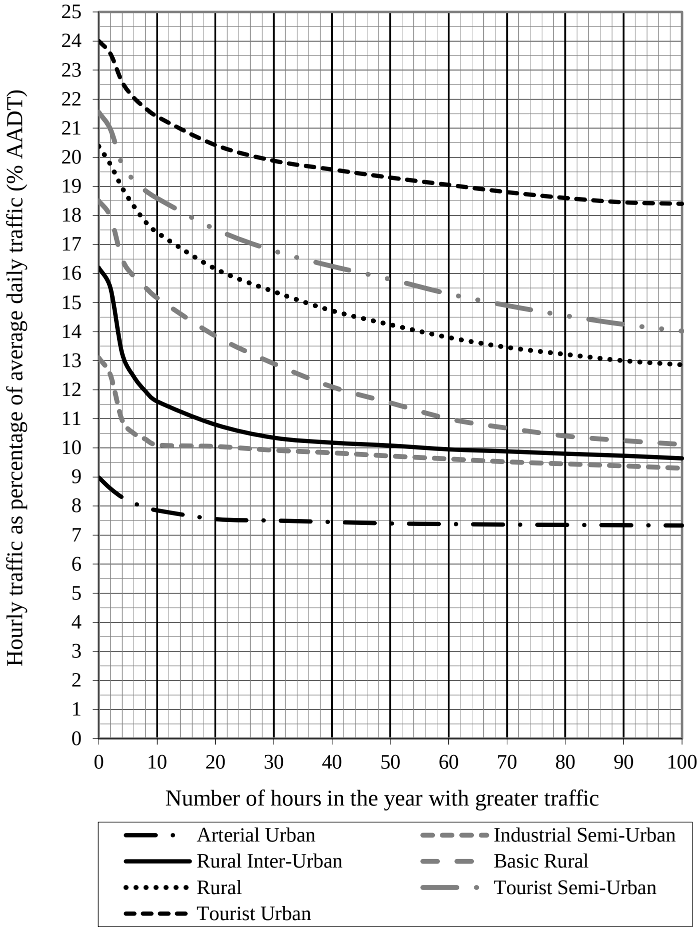

Fig. 3. Hourly distribution of traffic (K factor) based on facility type (Kraemer et al., 1984).

Finally, it is important to keep in mind the time lag between the moment at which the upgrade threshold is reached and the point in time when the upgraded facility is open to traffic. As detailed in Table 5, a reasonable estimate of the time required to accomplish the different steps involved in conversion of a two-lane highway to a four-lane facility should be around 48 months (four years) according to the Spanish practice.

Table 5. Steps required to upgrade a two-lane highway and estimated time according to the Spanish practice.

Step	Estimated time (months)
Drawing up internal proposal	2-4
Consultation with public bodies	Variable
Detailed planning	6
Public information and environmental impact assessment	6-8
Detailed design	6-9
Construction	18-20
TOTAL	42-48

6. Conclusions and recommendations

Based on the analysis conducted in this study, the following conclusions on a threshold to trigger the upgrade of a two-lane highway could be drawn:

- For the Madrid Region, an annual average daily traffic (AADT) of 10,000 veh/day is too conservative, and adopting it would result in need for excessive resources to upgrade well operating two-lane highways. Note that there might be other reasons to upgrade a facility, such as safety or continuity of major itineraries in the road network, but such decision should not solely rely on traffic volume.
- Capacity is rarely observed in two-lane highways so it does not seem an adequate criterion to establish an upgrade threshold.
- In establishing a threshold value, agencies should be mindful of the time lag between the decision to upgrade and opening to traffic is around four years.
- For rural segments, 15,000 veh/day (average value found in traffic volume distribution) is conservative, and a threshold of 18,000 veh/day (close to the third quartile) could be adopted, especially when heavy vehicles are not a concern (negligible number of heavy vehicles in peak period or level terrain).
- Values above 20,000 veh/day can be reached, particularly in urban environments, but not across the board.
- For roads with tourist traffic, a value under 15,000 veh/day could be adopted, considering the heavy asymmetry in demand: not much in a 15 minute period, but several hours on certain days.
- Service volume tables seem to work well, but users are warned against adopting the values for LOS E in HCM 2010 and LOS D in FDOT service volume tables.

Appendix A. Information on facility segments selected for study

No.	Facility	Type	Start point	End point	AADT (veh/day)	Year
1	M-108	Upgraded	A-2 P 20	Torrejón Air Base	12,891	1998
2	M-115	Upgraded	A-2 P 17.5	M-108 P 2.5 (Torrejón Air Base)	11,292	2004
3	M-408	Upgraded	A-42 P 20 (Parla)	M-506 (Pinto)	18,058	2004
4	M-501	Upgraded	M-600 (Brunete)	M-510 (Chapinería)	17,458	2004
5	M-503	Upgraded	M-40	M-50 (Majadahonda)	13,883	1999
6	M-506	Upgraded	A-4 P 23 (Pinto)	M-841 (San Martín de la Vega)	9,729	2002
7	M-616	Upgraded	M-607 P 17	Alcobendas	19,509	2003
8	M-103	Two-lane	M-106 (Algete)	M-117 (Fuente el Saz)	10,374	2008
9	M-111	Two-lane	Barajas	P 9, M-103	19,432	2008
10	M-113	Two-lane	M-111 P 3	M-114 (Ajalvir)	11,724	2008
11	M-119	Two-lane	A-2 P 30	M-116 (Camarma de Esteruelas)	17,132	2008
12	M-121	Two-lane	A-2 P 32.5	M-116 (Meco)	14,073	2008
13	M-203	Two-lane	M-208	M-300	15,263	2008
14	M-206	Two-lane	Loeches	M-225	10,721	2008
15	M-206	Two-lane	M-203	M-206 P 8	24,668	2008
16	M-208	Two-lane	M-203 P 10 (Mejorada)	P 5 (Velilla de San Antonio)	8,359	2008
17	M-209	Two-lane	M-300 (Arganda del Rey)	P 5 (Campo Real)	12,218	2008
18	M-300	Two-lane	P 15, M-224	P 22, M-220 (Los Hueros)	8,732	2008
19	M-300	Two-lane	P 22 (Los Hueros)	P 23.5 (Alcalá de Henares)	24,708	2008
20	M-305	Two-lane	A-4	Puente de Aranjuez	24,345	2008
21	M-404	Two-lane	P 20 (Griñón)	A-42 (Torrejón de la Calzada)	15,879	2008

22	M-404	Two-lane	A-4 P 30	M-307 P 7.5 (Ciempozuelos)	19,254	2008
23	M-405	Two-lane	Humanes	Griñón	8,726	2008
24	M-415	Two-lane	M-404 P 17 (Griñón)	Region border	17,182	2008
25	M-421	Two-lane	M-40	M-425 (Leganés)	13,051	2008
26	M-507	Two-lane	M-600 (Navalcarnero)	M-530 P 9 (Villamanta)	11,311	2008
27	M-508	Two-lane	M-503 (Aravaca)	M-502 (Húmera)	12,544	2008
28	M-509	Two-lane	M-50 (Majadahonda)	M-851	15,430	2008
29	M-510	Two-lane	A-6	Galapagar	12,164	2008
30	M-600	Two-lane	A-6 (Guadarrama)	M-533 (Peralejo)	20,738	2008
31	M-601	Two-lane	Villalba	M-863	16,450	2008
32	M-607	Two-lane	Colmenar Viejo	Cerceda	16,308	2008
33	M-609	Two-lane	Colmenar Viejo	M-862	19,955	2008
34	M-832	Two-lane	A-3 P 21	M-506	10,389	2008
35	M-851	Two-lane	M-50/M-505	M-509	8,436	2008
36	M-856	Two-lane	A-5 (Móstoles)	M-506	17,958	2008

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