

THE MADRID CASE STUDY: THE HOV-BUS SYSTEM.

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ABSTRACT

The HOV-BUS System has already proven to be a very efficient intervention to manage mobility in a metropolitan corridor with a relevant effect on the increase of bus users and with the increase of private vehicles occupation as well.

It is relevant to highlight that Madrid system is unprecedented as it is an intervention with four very important elements: HOV-BUS platform, ONLY-BUS lane in the final part reaching Madrid; underground interchange station for buses and very good Metro and Bus lines for the passengers to distribute all over the city

1. PRESENTATION OF MADRID CASE STUDY

1.1 Metropolitan region and transport system

The Madrid Region (Comunidad de Madrid) is one of the 17 Spanish Autonomous Regions with a population of 6,4 million inhabitants (January 2009 data) living in an area of 8.028,5 km², that is composed of 179 municipalities located in three functional areas (or rings):

- **Madrid city:** The largest city and municipality and the focal point of the region
- **The metropolitan ring:** Consisting of closely linked medium - sized and large municipalities, located in the metropolitan area immediately around the city of Madrid
- **The regional ring:** consisting of a number of small and medium sized municipalities.

In the last 40 years Madrid Region has registered an intense and continuous expansion process and territorial transformation, from the center of the city to the suburbs, which seems to continue in the future. Thus with these growth rates, we can see how from 2005 to 2025 Madrid municipality will grow 4,4%, but the first metropolitan ring will do 27,8 % and regional ring 62,9%. These changes mean a greater demand for mobility and a considerable increase in journey frequencies.

In the metropolitan areas the population has located in the territory along the radial trunk corridors of the main national roads (A-1, A-2, A-3, A-4, A-5 and A-6) and also the suburban rail corridors, which are very similar, almost parallel. Nowadays the population of the region locates almost equally half in Madrid city and the other half in the rest of the region.

1.2 Transport system and mobility demand

From the analysis of case studies, concerning Madrid land use and transportation networks densities compared with those in Tokyo and Paris, come clear a finding about Madrid mobility pattern: modal split is one third for each walking, private transport and public transport, and that regarding in Paris and Madrid regions the average distances a

generally high and also trip times too (from 22 to 25 minutes by car and almost double for mass transit).

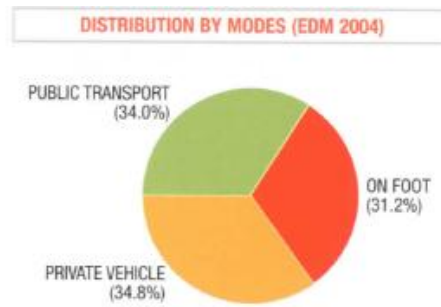


Figure 1 - Distribution by Modes in Madrid Region

We have seen that the modal share of the railway transports in Madrid is higher than in Paris and the modal share of mass transit Madrid is characterized by use of buses and coaches twice as high as for Paris without deteriorating the modal share of mass transit. Below are shown figures concerning all public transport modes operating in Madrid Region.

PUBLIC TRANSPORT SYSTEM DEMAND IN MADRID REGION IN 2009 (in millions)				
	Tickets	Trips	Stages	Trips-km
Metro	650	650	980,2	4.543,5
Buses	426,4	375	426,4	1.650,2
Railway Concesions	23,0	23,0	23,0	218,8
Road Concesions	245,2	233,9	245,2	3.690,3
Railway Cercanías RENFE	184,0	184,0	229,3	3.571,4
Total	1.528,6	1.465,9	1.904,1	13.674,2

Figure 2 - Public transport demand in Madrid Region

2. THE A-6 CORRIDOR

The A-6 road metropolitan corridor is the northwest access to Madrid city and a predominant residential area that has an especial importance in the region because it is considered the best environmental quality being surrounded of several natural protected parks, becoming the metropolitan corridor with the highest growth, reaching 565.808 inhabitants. Another important characteristic of this corridor in its low population density, of 427 inhab/km², considerably less than the region average that is 795 hab/km².

Year	1975	1986	1996	2006	2009
Population	103.587	180.546	312.456	515.805	565.808

Figure 3 - Population growth in A-6 corridor

2.1. The public transport system in the A-6 corridor

In the A-6 corridor there is a suburban railway line that goes along the edge of a regional protected park and that is also a nature reserve. This has produced that the growth of metropolitan municipalities around the railway stations being limited by the borders of natural park, in consequence, the population coverage around the stations of this rail line is the lowest in the Madrid rail network, only the 3,2% of population of this corridor lives in

a 300 meter radius and a 12,1% 600 m radius from the stations. Two suburban rail lines operates in this infrastructure giving service to 17 stations, five of which have paying park and ride facilities.

As part of this transportation corridor, the A-6 national road is a main motorway having two different platforms with three lanes each, plus a service road along the route through the metropolitan area that allows in and out entrances to the main road and accesses to the residential areas, connecting also with other roads.

In the A-6 road was built a high occupancy vehicles (HOV-BUS) system that was opened to the traffic in december 1994. It is located in the middle of the motorway and it is separated from the general road by means of rigid barriers. The in/out access to the road is made, as well as through both ends, through three intermediate points, named "embarking points" that give access to the middle of the road formats left side by means of a tunnel under the platform. The embarking points are situated in Aravaca (P.K. 9,5), El Plantío (P.K. 15) and Las Rozas (P.K. 18), being the first (closest to Madrid) exclusive for buses. The HOV-BUS system has no intermediate stops for buses once they get into he platform.

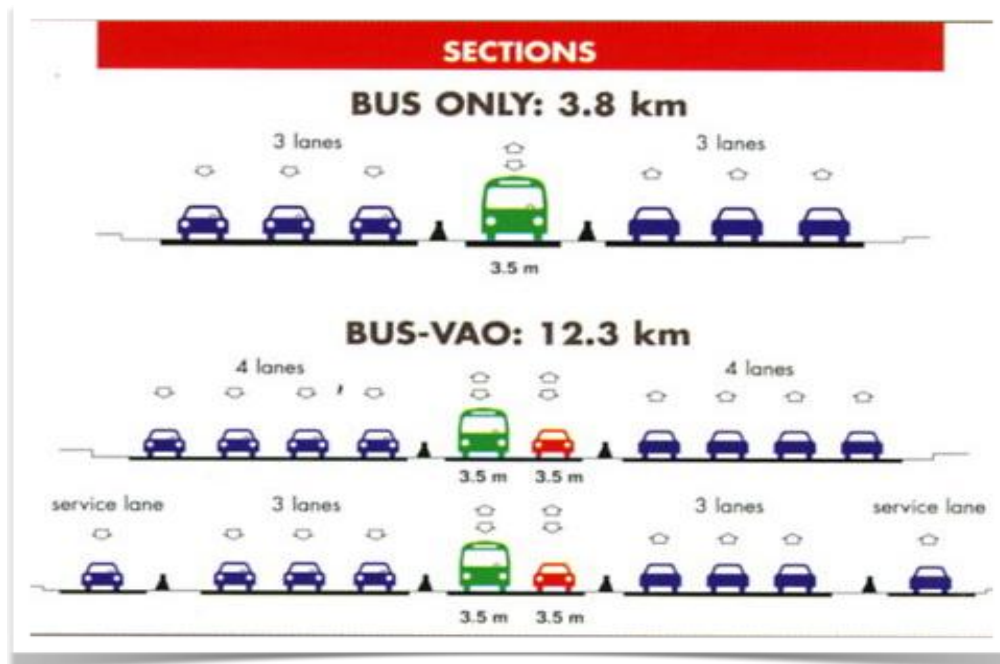


Figure 4 - The A-6 motorway cross sections with VHO-BUS lanes

The A-6 corridor also has an extense suburban bus network, 44 lines, of which operation is given in concession to private companies as in the rest of the Madrid region corridors. These bus lines make the public transport accessible to the city the various residential areas and new housing developments, all of them finish in the Moncloa interchange station. The system functions in a reversible manner (with traffic heading towards the city in the morning and towards outlying areas in the afternoon and evening). As told before the access points to the BUS-VAO system are located at these two end points (the beginning and end of the section) and via 3 intermediate, underground boarding points, connecting the left-hand side of the motorway with the central section. The performance of the system since its inauguration in 1994 has been highly satisfactory. More than 110,000 passengers use buses on this road each day, with more than 178 buses per hour and 8000 passengers in rush hours.

The general pattern is the following:

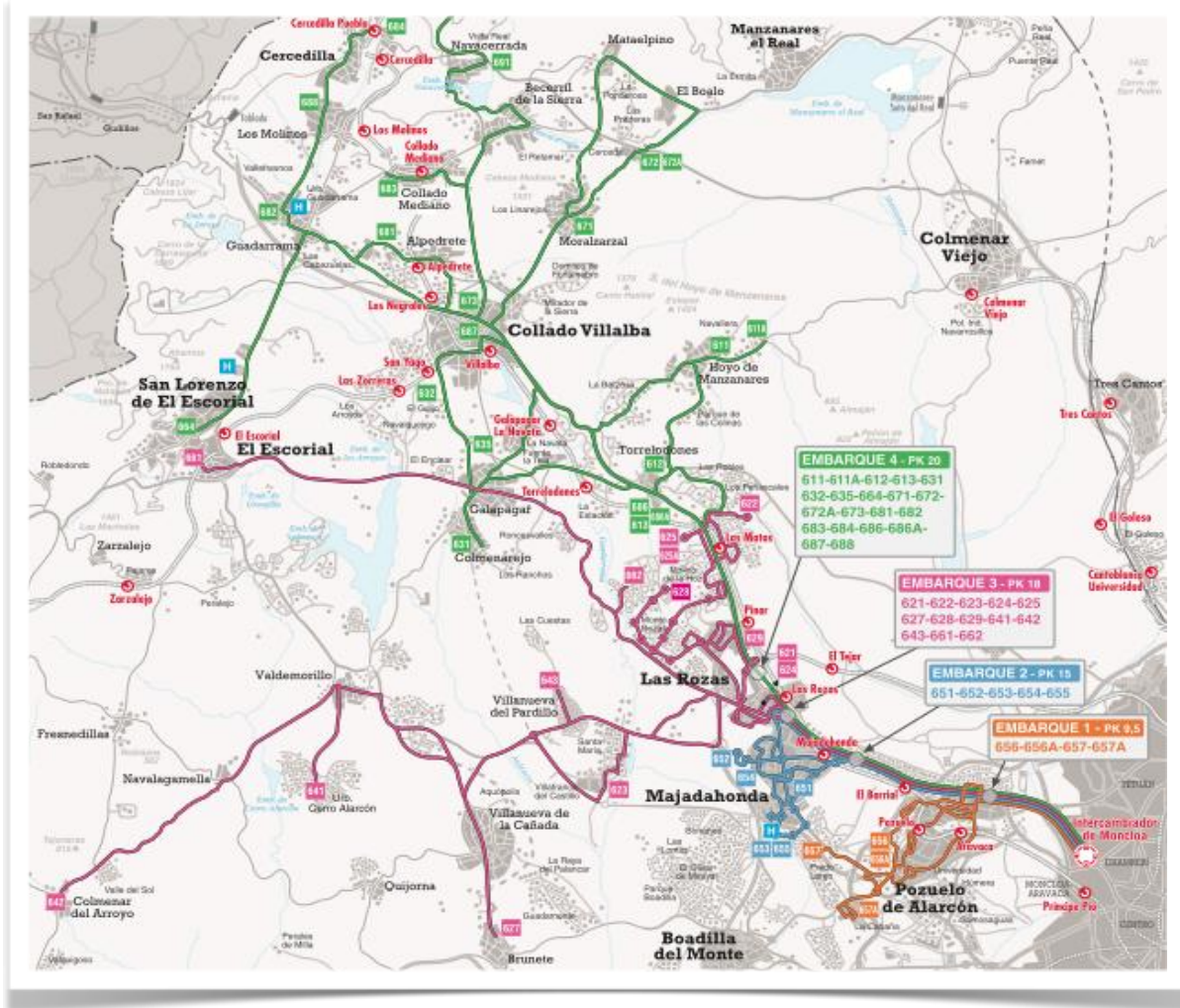


Figure 5 - Bus-lines feeding the HOV-BUS system in A-6 corridor

1. 4 bus lines networks supply towns in the northwestern suburbs and are organized as follows :
 - a. green: 21 lines (252 buses) to the towns in the outer northern suburb
 - b. pink: 14 lines (141 buses) to the towns in the outer western suburb
 - c. blue: 5 lines (38 buses) to the towns in the sector of Majadahonda
 - d. orange: 4 lines (60 buses) to the towns in the inner suburb

These 44 lines converge towards the highway respectively to kilometre points 20, 18, 15 and 9,5 (embarking points). From the moment they get in the highway they do not stop and go directly to the Moncloa interchange situated at kilometre point 0.

2. The highway is designed and operated not only to maintain good flow conditions but also to maximize riders traffic per lanes and therefore the public utility:
 - a. between kilometre points 20 and 15 traffic is generally fluid and buses do not run on reserved lanes
 - b. between kilometre points 15 and 3.8:
 - i. two reversible lanes reserved for buses built on the central reserve
 - ii. on weekdays, it is used only in the most congested way (incoming in the morning and outgoing in the evening)
 - iii. to return, buses have no reserved lanes

- iv. this reserved lane is accessible to high occupancy vehicles (two or more occupants) and motorcycles,
 - c. between kilometre points 3,8 and 0:
 - i. one reversible lane reserved
 - ii. on weekdays, it is exclusively used by buses and coaches
3. The interchange is a multimodal station that links in particular suburban bus lines to two metro lines:
- a. a radial line number 3 serves the centre of Madrid
 - b. a circular line number 6 enables the spread of riders towards different directions.

The coordinated organization between the bus network in the northwestern suburb of Madrid, the control of free flow on the HOV-BUS lanes of the highway A-6 and the interchange with two metro lines in Moncloa modal interchange station is an optimal combination of different transportation infrastructures. This system has the double objective of boosting the bus public transport operating the A-6 metropolitan corridor and also to promote carpooling.



Figure 6 - HVO-BUS lanes near access Moncloa modal interchange station

Efficiency of this set of measures is illustrated by the following table:

Morning peak hours between 7am and 10am	Flow per hour per lane		Mass transit lanes
	Side lanes	VAO lanes	
Veh / MPH			
PC	1216	1440	0
bus	6	68	136
total	1223	1508	136
Pass / MPH			
PC	1375	2558	0
bus	92	2943	5886
total	1467	5501	5886

Figure 7 - Mobility data and modal share in A-6 corridor.

On average over the peak hours in the morning:

- buses running every 40 seconds carry almost 3.000 riders per hour almost 8.000 in rush hours
- opening the HOV lane to vehicles with more than two people on board enables also to accommodate 1.440 vehicles per hour (ie more than congested lanes of the highway A6), which carry more than 2.500 additional riders per hour
- as a total each of the two lanes of the HOT lane flows 5 500 riders per hour ie 3,75 times more than conventional lanes of the highway A-6.

Also can be seen the effects in modal share. In the figure 8 are shown different mobility data taken over the past years both in the bus network and suburban rail network which allows to analyze the effects of the HOV-BUS system over these years.

	BUS/HOV PLATFORM			REGULAR LANES			SUBURBAN RAIL		
	BUS	OTHER	TOTAL	BUS	OTHER	TOTAL	Pozuelo - Aravaca	Tejar - Pitis	TOTAL
Nov 1991				6.602	21.430	28.032	2.611	7.902	10.513
Nov 1992				n.d.	n.d.	n.d.	2.386	10.373	12.759
Nov 1993				n.d.	n.d.	n.d.	2.361	12.798	15.159
Nov 1994				n.d.	n.d.	n.d.	1.601	13.698	15.299
Nov 1995	10.430	12.471	22.901	1.170	11.371	12.541	1.921	10.830	12.751
Nov 1996	10.905	11.823	22.728	1.115	16.945	18.060	5.418	9.250	14.668
Nov 1997	12.050	10.979	23.029	1.865	15.041	16.906	5.796	8.205	14.001
Nov 1998	12.040	13.100	25.140	910	15.792	16.702	5.465	7.543	13.008
Nov 2001	14.110	13.059	27.169	2.110	16.353	18.463	3.846	8.535	12.381
Oct 2008	17.634	15.838	33.472	838	17.463	18.301	6.097	8.204	14.301

Figure 8 - Passengers evolution in A-6 corridor. 7:00 am-10 am data

2.2. Effects in HOV-BUS platform

The massive territory coverage given by the buses plus HOV-BUS platform advantages was immediately appreciated by the people living along the A-6 corridor and still is. The record is in more than 10.000 passenger en rush hour and direction with almost 200 buses in service. Also very important is the private vehicles occupancy increasing, with an average occupancy index in the A-6 corridor of 1,6 occupants per vehicle; 2,1 in HOV-BUS lanes and 1,2 in regular lanes.

2.3. Effects in A-6 Regular Lanes

The opening of HOV-BUS platform had an important effect in the amount of vehicles that enters Madrid through this corridor during the last 15 years. On the regular lanes there are less vehicles than before partially because the HOV-BUS system but also because the existence of alternative roads as M-40 and M-50 speedways that were not as developed as they are now.

2.4. Effects in suburban rail

Regarding rail network it has been observed an important increase of the demand before the opening of the HOV-BUS System during 1993 and 1994 with growths near the 50% in four years, partially because the roadworks in the corridor.

The opening of the HOV-BUS system in 1994-1995 brought an important impact in rail network with a decrease in demand of 17% and during the next years has recovered part of that loss but never reached again the levels of 1994, even with a relevant population increase.

3. THE MONCLOA TRANSPORT INTERCHANGE STATION

The Moncloa transport interchange station was built in 1995, it was the first to be opened, serving the A-6, La Coruña motorway corridor, and has been an impressive success, not only in itself, but also because of several other measures which were taken at the same time, such as the arrival of Metro line 6, making Moncloa the busiest Metro station on the network, and the opening of the bus and high occupancy vehicle only lane for the A-6 motorway.

Passengers do not have to travel to stations on the outskirts of the city to use inter-urban bus services, as the Moncloa transport interchange station is located in the centre of the city and connects directly to Metro line 6, the Circular line that travels around the centre of the city and links to all of the key points on the Metro Network. However, as the potential operating companies were not convinced that the new station would be profitable upon its proposal, this first underground transport interchange station was funded entirely from public funds; as a result, the design of the station had to be limited to what was only strictly necessary for operation under normal conditions in order to stay within the available budget.

The initial and continuing success of this development (the HOV-BUS lane, the opening of Metro line 6 and the Moncloa transport interchange station) resulted in a spectacular increase in demand for public transport at the transport interchange station; as a result, Moncloa is currently the busiest Metro and inter-urban bus station in the city. There has been a substantial increase in the services offered since the transport interchange station was opened, from 1.603 journeys in 1995 to over, 4.100 journeys today.

These continuous increases have brought the transport interchange station close to its saturation point during rush hour, which has resulted in numerous traffic problems at the entrance to Madrid, leading to extended journey times, and excessive pollution and temperatures for passengers.

In addition, population growth to the west of the city suggests that transport demand will increase rapidly in the near future. The population of the A-6 corridor increased by 33,3% from 1991 to 1996, and the land use plans for the area forecast a population of 344,256 in 2006, an increase of 19% compared to 1996

Due to the station's complete saturation and the growth in demand within the A-6 motorway corridor the old Moncloa transport interchange station built in 1995 had to be expanded below the Arco de la Victoria (Arch of Victory) island, as it was planned in the approved Transport Interchange Station Plan for Madrid city.

The station's location in the city's centre, in a zone of intense traffic during rush hour and a monumental urban environment between the Arco de la Victoria (Arch of Victory), the District City Hall and the Air Force Headquarters, bordering the Park del Oeste and the green zones of the Complutense University, has influenced both the construction, which has been done with extreme caution to minimize potential impacts, and the design and location of the exterior elements.

The expansion of the Moncloa transport interchange station was carried out to relocate the Metro line 3 station to the same level as the line 6 station so as to improve passenger transit and provide parking spaces for bus inspections, together with new installations and equipment.

This development was essential in order to carry out the expansion of the station below Arco de la Victoria (Arch Module), as it freed up the required space that had previously been used for the Metro line 3 station and its garages.

At the situation prior to the expansion, the area of the previous transport interchange station was limited by the course of the Metro line 3 and the car parking lot opposite the Air Force Ministry Building, with expansion being possible only in the area bounded by the screen walls of the transport interchange station and the buildings on Princesa street, located in this area.

Pedestrian space was amplified and improved, creating a two-level plaza. The existing platform in front of the District City Hall became a walking zone and an access vestibule to the building and the interchange station via two elevators. The new platform (or interchange station cover) became a pedestrian standing zone that faces northwards towards the mountains, as a "lookout station". Following is the main data for the expansion of Moncloa transport interchange station:

- Investment of 112,78 million Euros.
- Construction of 46,000 m², separated into two floors.
- Increase of the number of bus bays from 20 to 36 and regulation areas with completely underground entrances to the three islands from the bus lane in the A-6 motorway.
- Physical separation of the air-conditioned pedestrian island the buses.
- Additional complementary services.
 - Once the extension has been completed (the Arch module) and the original transport interchange station (the Calle Princesa module) has been completed, the new station will consist of four levels:
 - Level 0: Access at street level (657 m above sea-level).
 - Level -1: The bus station (651 m above sea-level).
 - Level -2: The hall connecting the bus station, the Metro and the shopping area (646 m above sea-level).
 - Level -3: The platforms for Metro line 6 (641 m above sea-level).
 - Surface level. Access
 - The impact of project at surface-level in this zone was minimal. The paved areas and gardens that were affected by work were restored to their original conditions.
 - The developments on the surface are mainly functional in nature: expansion of the current access building towards Paseo de Moret, to be used for the location and improvement of climate-control facilities, new access to the Metro station, which connects to the new Metro station entrance hall at a level of +646.20m above sea-level, redevelopment of the old access to the Metro station from Calle Princesa,

construction of new emergency stairs on the western side with the Paseo de Moret-exit, and development of the gardened areas in front of the Air Force Ministry building.



Figure 9 - Moncloa modal interchange station. Surface Level.

The Bus Station. Level -1:

The bus station is 651 m above sea-level, on level -1 of the Moncloa transport interchange station, 6 m below the main entrance and beneath the Princess street and the pedestrian plaza. The area for passengers is a pedestrian space surrounded by a ring road. It currently has 15 parking bays for buses, two of which are for articulated buses and one for alighting passengers.

Metro line 3:

Metro line 3 runs very close to the surface from the municipal district of Moncloa – Arvada to the Arco de la Victoria (Arch of Victory). The curved design of the platforms, which resulted in the 90° turns compared to the Called Princes, together with the train garages and repair shops, which were parallel to the platform, had made it impossible to expand the transport interchange station towards the Arco de la Victoria and to provide direct access to the transport interchange station from the Bus-VHO lane.

The Arch module:

This development took place in the Arco de la Victoria plaza, which is entirely surrounded by roads. It enabled vehicles from the A-6 motorway to enter the city. There are two underpasses; one facilitates the exit towards the A-6 motorway while the other is for the bus-only lane.

The Bus Station Level

The new transport interchange station is accessed during rush hour in the morning (priority given to arrivals) using the Bus-HOV tunnel that joins module B directly from the A-6 motorway and unloads passengers in the alighting bays in islands 2 and 3 (module B), or on island 1 of module A. After unloading their passengers, the buses move to the appropriate bus bays to pickup new passengers and then depart from module B using the side ramp. This is parallel to the A-6 tunnel to Cardenal Cisneros, or from module A using the current ramp.

At peak time during the afternoon (priority for departures), the direction of travel for the Bus-HOV tunnel is reversed and buses enter the transport interchange station using the western side ramp to module B; from there they move to module A through the interior.

The unloading bus bays are located close to the vertical communication units, and the stairs between level 0 and -1 and between -1 and -2 are displaced on their axes to shorten the distance that passengers have to travel.

The passenger islands are a fundamental aspect of the design of the new transport interchange stations, so the passenger areas are deigned independent of the bus areas, in order to make it possible to control climatic conditions in the passenger areas, protecting them from noise and fumes from the buses and, in the event of a of a fire on a vehicle, to stop smoke from entering these areas.

Mobility

In 1995, the Moncloa transport interchange station served 26 inter-urban bus routes, with over 1.603 journeys per day, over 125.000 passengers per day, and 310 journeys per hour between 8:00h and 10:00h. Today are served 20 urban bus lines, 56 interurban bus lines (in the A-6 motorway), 1 long distance bus line with a demand of 287.000 passengers per/day and 4.100 journeys per day.

The -urban bus routes serve 125.000 passengers per day, with 4.141 bus journeys. Demand for the Metro has likewise increased from 44.076 journeys per day in 1995 to over 170.000. The HOV-BUS System has already proven to be a very efficient intervention to manage mobility in a metropolitan corridor with a relevant effect on the increase of bus users and with the increase of private vehicles occupation as well.

It is relevant to highlight that Madrid system is unprecedented as it is an intervention with four very important elements: HOV-BUS platform, ONLY-BUS lane in the final part reaching Madrid; underground interchange station for buses and very good Metro and Bus lines for the passengers to distribute all over the city.

4. BUS RESERVED PLATFORMS ON NATIONAL ROADS AND MODAL INTERGHANGE STATIONS

Due to the importance of the interurban bus network for mobility between the greater metropolitan region and the city of Madrid, the public transport administration in Madrid, CRTM, has been strengthening this network for years, not just in terms of improving the quality and quantity of services offered by means of new lines, better buses, etc., but also by carrying out specific programs to foster this mode of transport.

This is the context in which two programs of wide-ranging scope are being developed: the Madrid plan for metropolitan bus terminal interchanges and the plan for bus reserved platforms on national and regional roads.

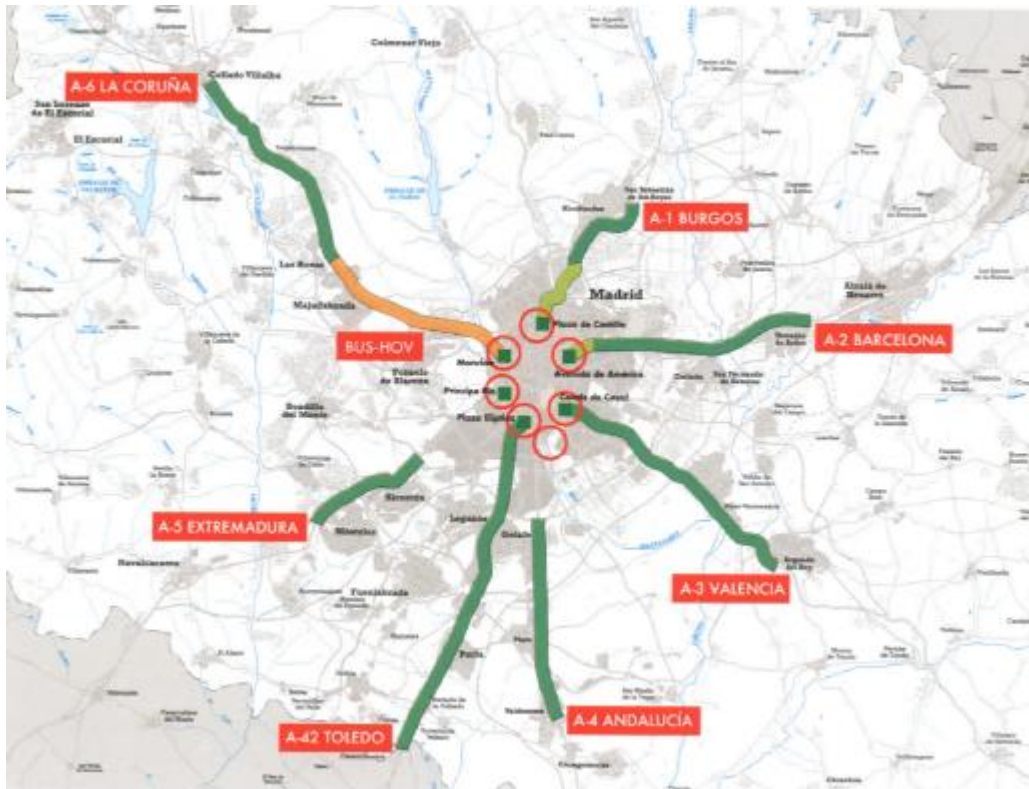


Figure 10 - Layout of bus interchange platforms on national roads.

The success of this initiative has resulted in the Ministry for Public Works considering similar solutions for other access roads into Madrid (the A-1, A-2, A-3, A-4, A-5 y A-42 as shown in figure 10). Some of these are already at advance study phase. This will give the towns located in the greater metropolitan area direct bus access to Madrid. The Region of Madrid has also planned a series of initiatives to complement the Ministry's program.

The initiative consist for all national roads of a system with 4 basic elements: the BUS-HOV lane for buses and high occupation vehicles; a BUS-ONLY section when approaching the city itself; an underground interchange, for the bus terminals; and a good connection with the metro system and the city as a whole, and a number of EMT bus lines (bus lines operating in the Madrid central core).

The system operates reversibly, with traffic heading towards the city in the morning and towards the suburbs in the afternoon and evening. It is located either in service lanes along both sides of the national road or in the middle of the dual- carriageway and is separated from the road by means of rigid barriers.

At the end of each road entering the city there is a bus terminal integrated in a modal interchange station that facilitates passenger changeovers between transport modes. The aim has been to integrate bus transport within the overall public transport system but particularly with the metro network. Bus terminal therefore need to meet certain conditions in terms of accessibility, space and integration with urban architecture.

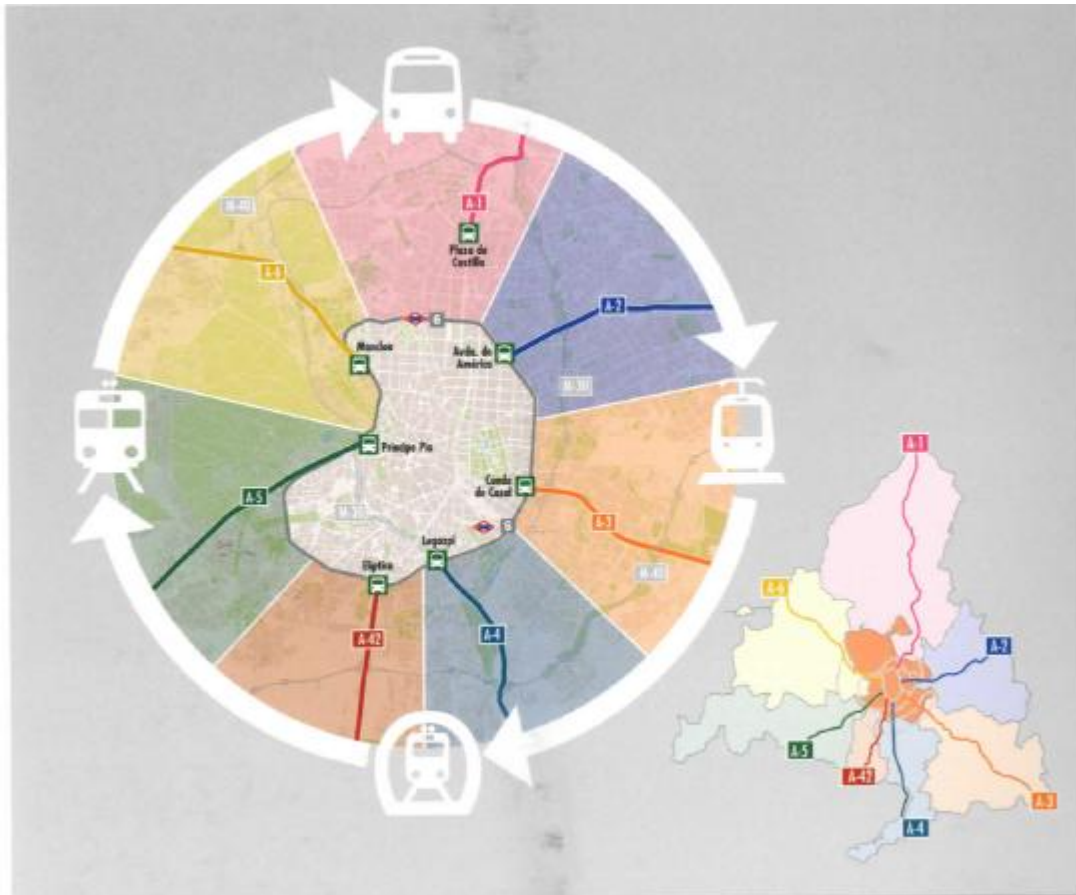


Figure 11 - Diagram of modal interchange stations on main national roads when entering Madrid city

	Plaza de Castilla	Avenida de América		Plaza Elíptica	Principe Pio	Moncloa
		Current	Extension			
National road	A-1	A-2		A-42	A-5	A-6
Investment(€millions)	143,9	24	43	54,5	56,3	113,9
Surface area (m ²)	59.829	40.548	6.350	40.200	28.300	46.000
Tunnels (m)	1.250	400	160	600	400	500
Total demand (pass/day)	179.645	167.720		76.633	198.807	287.081
No.of urban lines (EMT)	25	18		9	17	20
No.of intrurban lines	55	14		20	27	56
No. long-distance lines	-	19		1	2	1
No. of platforms	48	36		24	30	36
No. of park spaces	400	645		363	-	-
No. of Metro lines	3	4		1	3	1
No. of suburban rail lines	-	-		-	2	-

Figure 12 - General data on the main modal interchanges including bus terminals