Transport policy contribution to Sustainability in Madrid. A new assessing framework.

Miguel MATEOS, Paul PFAFFENBICHLER, Alfredo SÁNCHEZ

(CEDEX, Centro de Estudios del Transporte, c/ Alfonso XII, 3-5, Madrid, España, miguel.mateos@cedex.es
Technische Universität Wien, Institut für Verkehrsplanung und Verkehrstechnik, Gußhausstr, 30/231 A-1040, Wien, paul.pfaffenbichler@tuwien.ac.at
Universidad Politécnica de Madrid (UPM), TRANyT, c/ Profesor Aranguren s/n, Madrid, España, asvicente@ceminos.upm.es)

1 INTRODUCTION

Sustainability is one of today's major challenges. Numerous studies provide evidence that cities worldwide do not fulfil the requirements of sustainability. The work presented here investigates whether transport policies of the municipality of Madrid contribute to the high level objective of sustainability.

The case study Madrid region covers an area of about 8,000 km2 with around 5 million inhabitants. Land use is characterised by a rapid development of housing and businesses in the outskirts. As a result a high share of people commutes between the periphery and the core city, causing high levels of peak hour congestion. Indicators show that the land use and transport system do not fulfil the requirements of sustainability.

Different policy instruments were proposed to improve the situation. One is the extension of the metro line number 9 which was opened in 1999. Another is the current proposal to install bus lanes on all radial highways. One bus and high occupancy vehicle (HOV) lane already exists on the highway A6.

A framework to assess the contribution of these instruments to sustainability is suggested. It consists of an indicator based approach and a modified cost benefit analysis. The strategic, dynamic land use and transport interaction model MARS (Metropolitan Activity Relocation Simulator) is the core of the assessment framework. Effects on land use, regional travel patterns and transport emissions can be predicted with it.

Results are summarised and discussed. Conclusions are drawn and policy recommendations are given. Potential weaknesses and ways to overcome them are identified. Topics for future research are highlighted.

2 THE OBJECTIVE OF SUSTAINABILITY

A possible definition of sustainability is equity between today’s and future generations (May, et al. 2003). I.e. the activities of today’s generation should not limit or hinder the opportunities of future generations. Another definition is that a sustainable system *“does not leave any negative impacts or costs for future generations to solve or bear – present builders and users of the system should pay such costs today”* (Schipper, et al. 2005) Furthermore the use of a set of sub-objectives and indicators is suggested to make the general definition operational (May, et al. 2003, Schipper, et al. 2005): “Careful treatment of non-renewable resources”, “Protection of the environment” or “Equity and social inclusion” (May, et al. 2003).

This paper focuses on these three sub-objectives because the corresponding indicators can be calculated directly with the integrated land use and transport model MARS. Other sub-objectives like “Contribution to economic growth” cannot be taken into account. Macro-economic development is not within the scope of a regional model like MARS. Due to the strategic character of MARS it is not possible to calculate local indicators like noise and pollutant imissions. To overcome these limitations it is suggested to link MARS to models covering other levels of dis-aggregation.

2.1 Indicators of sustainability

(Minken, et al. 2003) and (Schipper, et al. 2005) suggest a wide range of indicators to assess sustainability towards its sub-objectives. Consumption of land, consumption of fossil fuels and atmospheric emissions are amongst them. Land and fossil fuel are non renewable resources. Hence their consumption is suitable as an indicator to measure the sub-objective “Careful treatment of non-renewable resources”. Local atmospheric emissions endanger the environment and are therefore suitable to represent the sub-objective “Protection of the environment”. Accessibility is seen as a proxy for the sub-objective “Equity and social inclusion”.

3 THE CASE STUDY AREA

Madrid is situated in the heart of Spain, covering an area of about 8,000 km2, and a population of around 5.4 million inhabitants, 2.9 million of them in the core city. Land use is characterised by a rapid development of housing and businesses in the surroundings. The population living there steadily increases. As a result a high share of people commutes between the outskirts and the core city. The share of car trips is higher during the peak period than during the rest of the day. Although Madrid has an efficient metro line system and 55% of the people commute into the city using public transport (CRTM 1996), this results in a high level of peak hour congestion. Both the land use and the transport system does not fulfil the requirements of sustainability.

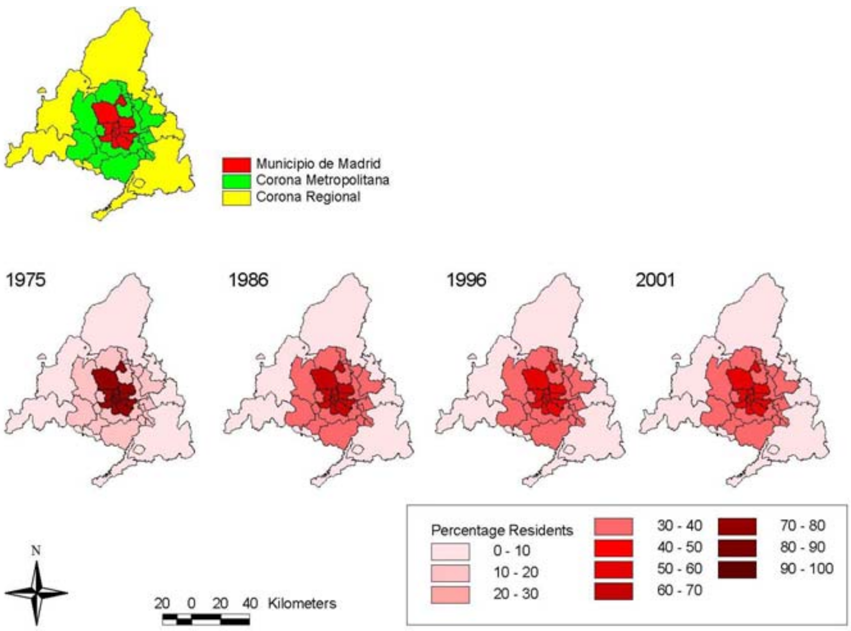

Figure 1: Development percentage of residents city centre and outskirts (CAM 2001)

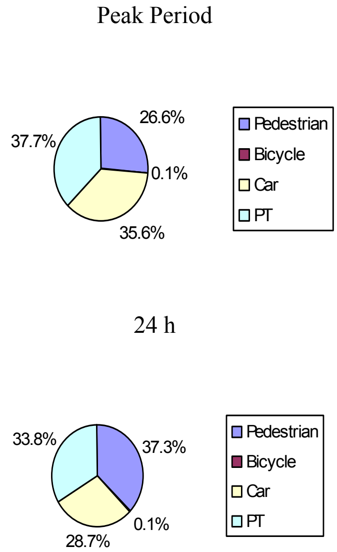

Figure 2: Modal share "Comunidad Madrid" in 1996 (CRTM 1996)

4 TRANSPORT PROJECTS

Different policy instruments have been proposed (and realised) to improve the situation described above.

4.1 Metro line extension

Rivas-Vaciamadrid and Arganda del Rey are situated in the corridor of the highway A3 in the southeast of the core city (see Figure 3, detail X). Due to the relative proximity many residents commute into the city of Madrid. As public transport was solely bus based the share of public transport trips was only about 21% in 1996 (CRTM 1996). The traffic situation was worsened by a rapid development of housing, service sector business and industry. Figure 4 shows the development of the number of residents.

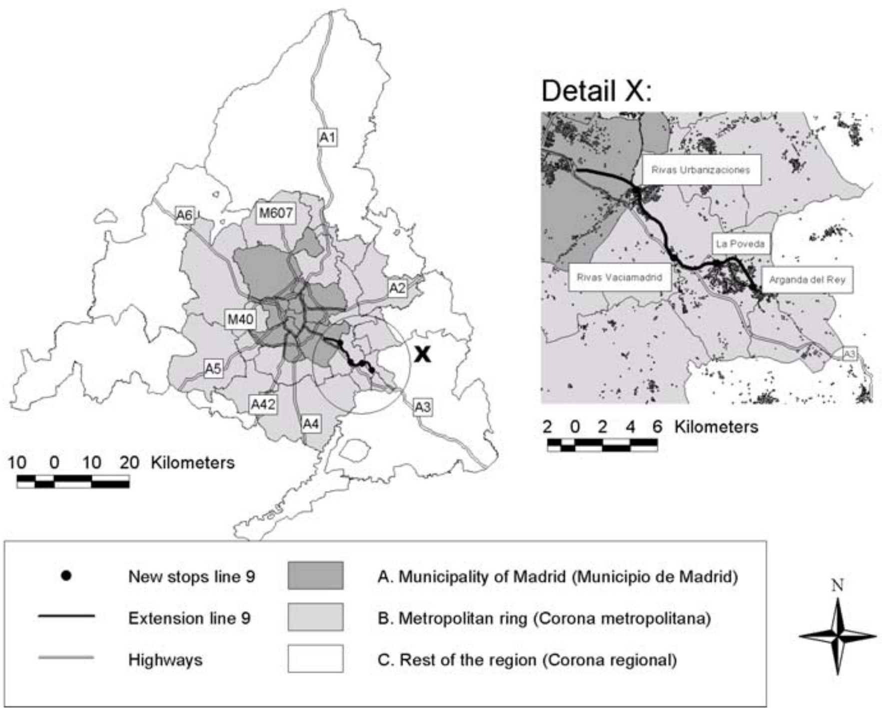

Figure 3: Extension of the metro line number 9

The municipality of Madrid reacted by deciding to extend the metro line number 9 from its former end station Puerta de Arganda until Arganda del Rey (Figure 3). This extension, opened in 1999, brought four new metro stations: Rivas Urbanizaciones, Rivas Vaciamadrid, Poveda and Arganda del Rey. Details about the planning process and funding have been published elsewhere (Monzon 2003, Monzon and Gonzalez 2000). A more detailed description is also given in (Vieira 2005).

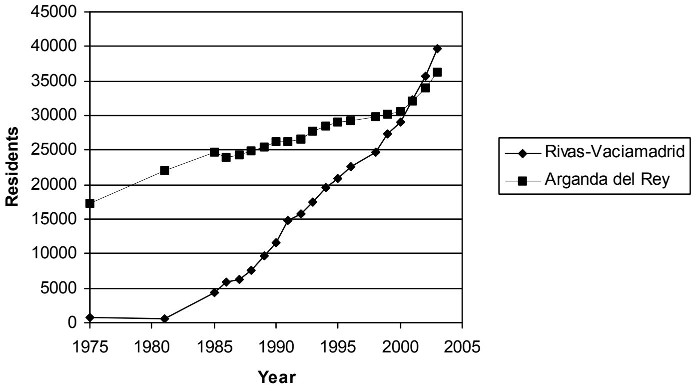

Figure 4: Residents in the corridor A3; Source: Instituto de Estadístico de la Comunidad de Madrid (Vieira 2005)

4.2 Bus and high occupancy vehicle lanes

A bus and high occupancy vehicle (HOV) lane exists on a 16 kilometres long stretch of the highway A6 (Figure 5). It consists of a 12.3 km reversible double lane from Las Rozas to Puerta de Hierro and a 3.8 km bus-only lane from Puerta de Hierro to the Moncloa interchange.

The system operates in a reversible basis with the following timetable:

Restricted access to buses and HOVs:

Inbound Madrid: from 6:00h to 12:30h Monday to Friday

Outbound Madrid: from 13:30h to 22:00h Monday to Friday

Unrestricted access on holidays and weekends.

There are three entries – inbound – or exits – outbound (Figure 5). Prior to the implementation of the bus/HOV facility, the A6 corridor was chronically congested. The opening of the bus/HOV lane in 1995 improved the situation. Peak travel times for bus and HOV lane users have decreased substantially (Figure 6 and Table 1). Greater reliability of suburban bus services has fostered their use. Bus patronage has increased significantly - from 24% in 1991 to 36% in 2001. The costs for the construction were about 56.6 million Euros (Pozueta Echavarri 1997), which equals 3.3 million Euros per kilometre.

Figure 5: Bus/HOV lane, stretches and access points (Monzón, et al. 2003)

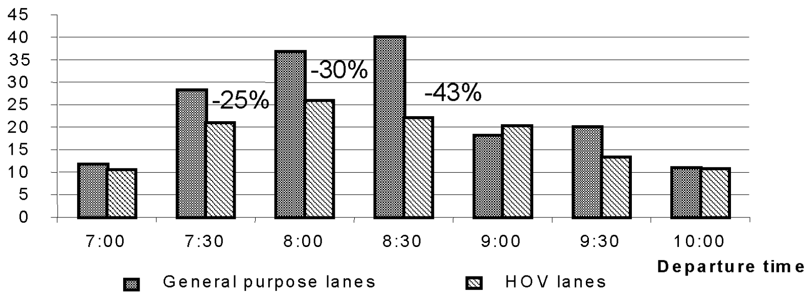

Figure 6: Travel time (minutes) for 15 km access road; A6 morning peak, 2001 (Monzón, et al. 2003)

Table 1: Travel time bus Las Rozas – Moncloa, average working day (Pozueta Echavarri 1997)

Period	1991	March 95		June 95		Nov. 95	
		(min)	(%)	(min)	(%)	(min)	(%)
07:00 – 08:00	26	11	-57.7	13	-50.0	16	-38.5
08:00 – 09:00	32	12	-62.5	14	-56.3	17	-46.9
09:00 – 10:00	27	12	-55.6	10	-63.0	11	-59.3

Recently the Spanish minister Magdalena Álvarez presented plans to construct more than 100 kilometres two-way bus lanes on all radial highways (Javier Barroso 2005). Details can be seen in Figure 7. There are two principle possibilities to construct bus lanes: either to build extra lanes or to dedicate existing lanes to bus use only. While capacity for cars stays the same with the first possibility, it is reduced with the second one. Both possibilities were used later in the case study. The scenarios are named “New Lanes” and “Replace Car Lanes” respectively. Currently no official cost estimates for the new bus lanes exist. The investment costs for building the bus lanes in the scenario “New Lanes” were estimated with 722 million Euros using costs of 3.3 million Euros per kilometre (Pozueta Echavarri 1997). The investment costs for the scenario “Replace Car Lanes” will be lower and were roughly estimated with 300 million Euros.

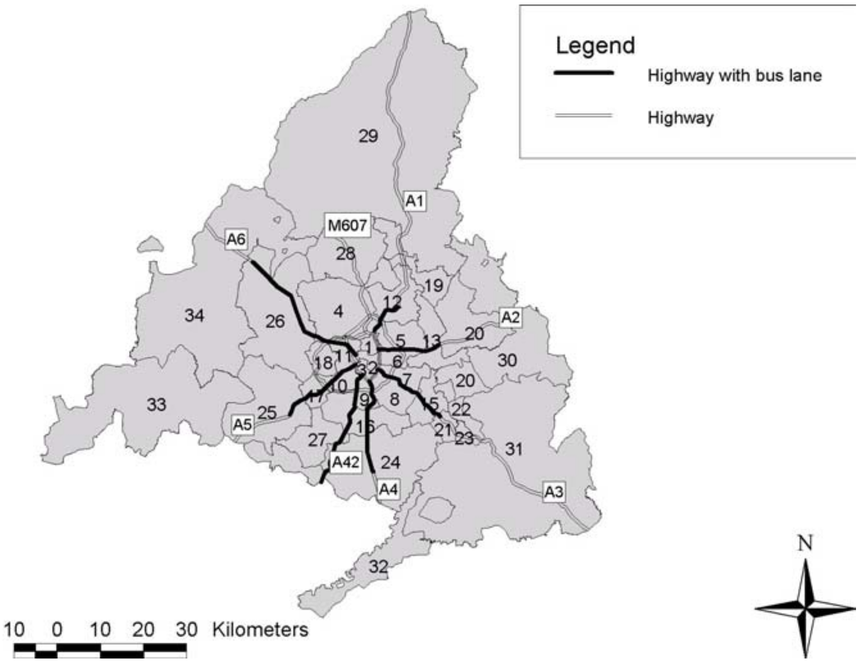

Figure 7: Proposed bus lanes in Madrid (Javier Barroso 2005)

5 THE INTEGRATED LAND USE AND TRANSPORT MODEL MARS

MARS is an integrated strategic and dynamic land-use and transport model. The basic underlying hypothesis is that settlements and the activities within them are self organising systems. Therefore it is sensible to use the principles of synergetics to describe collective behaviour (Haken 1983a, 1983b).

MARS assumes that land-use is not a constant. It is rather part of a dynamic system that is influenced by transport infrastructure. Therefore at the highest level of aggregation MARS can be divided into two main sub-models: the land-use model and the transport model. The interaction process is implemented through time-lagged feedback loops over a period of 30 years.

Two person groups, one with and one without access to a private car are considered in the transport model part. The transport model is broken down by commuting and non-commuting trips, including travel by non-motorised modes. Car speed in the MARS transport sub-model is volume and capacity dependent and hence not constant. The energy consumption and emission sub-models of MARS utilise speed dependent specific values. The land-use model considers residential and workplace location preferences based on accessibility, available land, average rents and proximity to recreation areas. Decisions in the land-use sub-model are based on random utility theory. Due to its strategic characteristic a rather high level of spatial aggregation is used in MARS. In most case studies this means that the municipal districts are chosen as analysis zones. The outputs of the transport model are accessibility measures by mode for each zone while the land-use model yields workplace and residential location preferences per zone.

MARS is able to estimate the effects of several demand and supply-sided instruments whose results can be measured against targets of sustainability. These instruments range from demand-sided measures, such as with public transport fare (increases or decreases), parking or road pricing charges to supply-sided measures such as increased transit service or capacity changes for road or non-motorised transport. These measures, furthermore, could be applied to various spatial levels and/or to time-of-day periods (peak or off-peak).

To date the model MARS was applied to seven European case study cities Edinburgh, Helsinki, Leeds, Madrid, Oslo, Stockholm and Vienna. Currently a MARS model of Lisbon, Portugal is set up within a PhD-thesis. Within the ongoing project SPARKLE (Sustainability Planning for Asian cities making use of Research, Know-how and Lessons from Europe) MARS is adopted and applied to the Asian cities Ubon Ratchasthani, Thailand and Da Nang, Vietnam (Emberger, et al. 2005). To test the model MARS an extensive back casting exercise was carried out with data of the city Vienna (Pfaffenbichler 2003). A full description of MARS is given in (Pfaffenbichler 2003).

A calibrated and extensively tested MARS model covering the "Comunidad Madrid" was set up in a PhD-thesis (Vieira 2005). As an example for the model testing the comparison of the MARS results for total daily trips with the results of the 1996 Madrid travel survey is shown in Figure 8. As well the fit as the slope of the linear regression between the MARS result and the statistical data is satisfying. This model was utilised for the case study presented in the following sections.

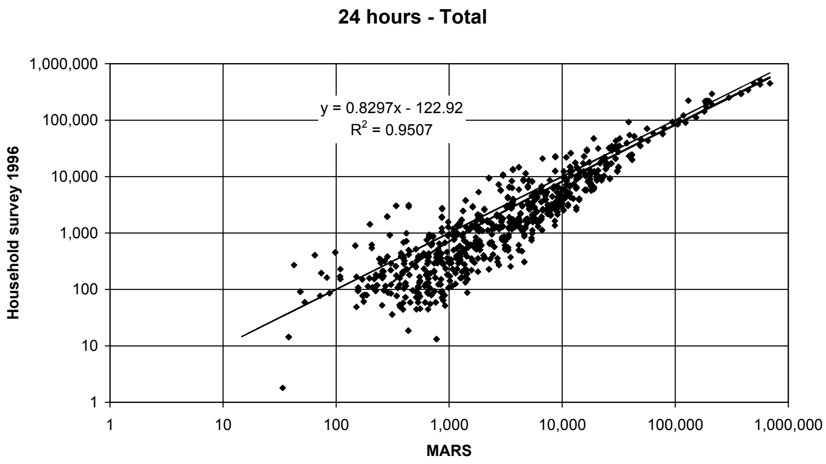

Figure 8: Comparison of the MARS model results with the results of the 1996 household survey (CRTM 1996) – daily trips total

6 RESULTS

A modified cost benefit analysis as laid out by (Minken, et al. 2003) was used to assess the effects of the transport projects towards the objective of sustainability. Furthermore the following indicators are used:

local emissions (NOX, VOC),

greenhouse gas emissions (CO2),

number of residents per zone and

accessibility per zone

6.1 Cost benefit analysis

Table 2 summarizes the results of the cost benefit analysis. The effects are assessed for the period 1996 to 2026. The interest rate was estimated with 6%.

The result of the scenario "extension of the metro line number 9" is slightly positive. The group, which receives the highest benefits, are public transport users. They gain time savings worth about 220 million Euros which is about 2/3 of all benefits generated. The group, which pays for the strategy, are public transport operators. They bear about 60% of total costs while receiving just about 7% of total benefits. Concerning land use property owners gain additional profit while property users have to bear higher costs. The environmental benefits account for about 5% of the total benefits.

Both bus lane scenarios result in a welfare surplus. But nevertheless there are differences. Both have in common that the positive result is driven by a highly positive value for public transport user time savings. Car user time savings are positive in the scenario "New lanes" and negative in the scenario "Replace Car Lanes". The same is true for car user costs. In both scenarios public transport operators create about the same revenues from additional fares. The government finances the investments in both scenarios. The total external costs are negative for the scenario "New Lanes" and positive for the scenario "Replace Car Lanes".

The present value of finance is negative for all three scenarios, i.e. they increase public spending compared to "Do minimum".

Table 2: Results of the cost benefit analysis (million Euros)

Source of costs and benefits			Value (million €)		
			Metro	Bus Lanes	
			Line 9	"New Lanes"	"Replace Lanes"
User	Public transport	Time savings	221.5	1,181.8	1,140.8
	Car	Time savings	-3.5	112.7	-255.1
		Money	4.0	33.3	-81.2
	Residences	Rent, mortgage	-123.5	-148.0	-340.7
Operator	Public transport	Investment	-113.3	-722.0	-300.0
		Operating costs	-77.6	-5.9	0.0
		Revenues	22.4	141.4	123.8
	Road	Maintenance	-0.4	0.0	0.0

	Residences	71.1	151.1	346.3
Government	Fuel tax, Parking	-8.5	1.3	17.7
Society (external costs)	Accidents, local emissions	10.2	-36.0	-5.5
	Greenhouse gas emissions	5.2	6.9	12.7
Total Objective Function		**16.6**	**716.6**	**658.8**
Present Value of finance (PVF)		**-177.4**	**-585.2**	**-158.5**

6.2 Metro line extension

The potential of the metro line extension to reduce overall atmospheric emissions is limited. For the local pollutants NOX and VOC it is only about -0.1% to -0.2%. The potential to reduce CO2-emissions is of the same order of magnitude. The reduction is about –0.2% in the years following implementation but decreases continuously to about –0.1% in the long run. At first sight results for local levels of NOX and VOC emissions are contradictory. Yearly emissions are reduced in the short term but increase significantly in the long term. There are two reasons for this effect. First more residents move into the corridor in the scenario “Line 9” than in the scenario “Do Minimum”. Therefore the number of trips and car trips increases to higher levels than in the scenario “Do Minimum” in the long term. Additionally car speed increases in the short run years due to the reduced number of car trips. Thus making travel by car more attractive and stimulating car use.

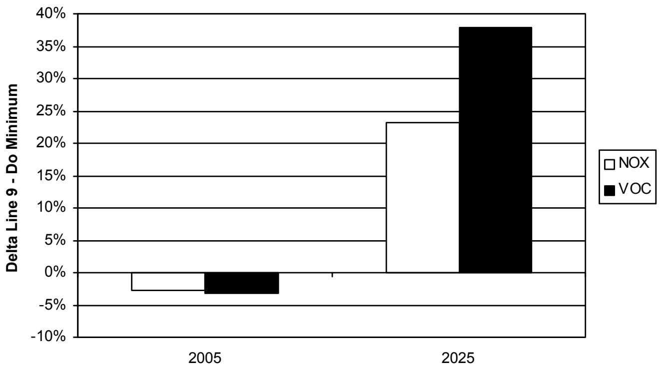

Figure 9: Difference in emissions caused by trips originating in the corridor A3

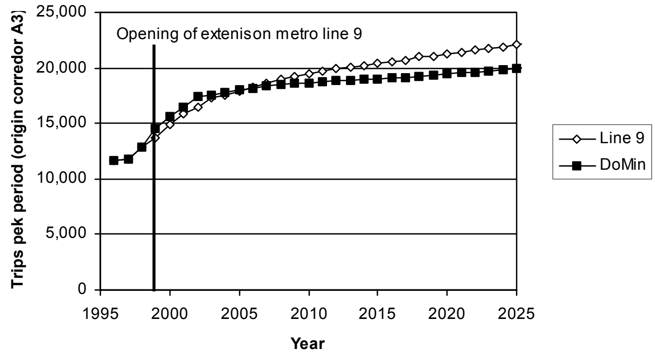

Figure 10: Number of car trips originating in the corridor A3

The metro line extension increases the attractiveness of Rivas and Arganda as a living place. In the scenario “Line 9” more people move into the corridor to live there (Figure 11). The decision where to settle within the corridor is determined mainly by two factors: the availability of land and the proximity to the metro line stations. Overall land consumption increases slightly due to the fact that development densities are lower in the corridor A3 than in the core city.

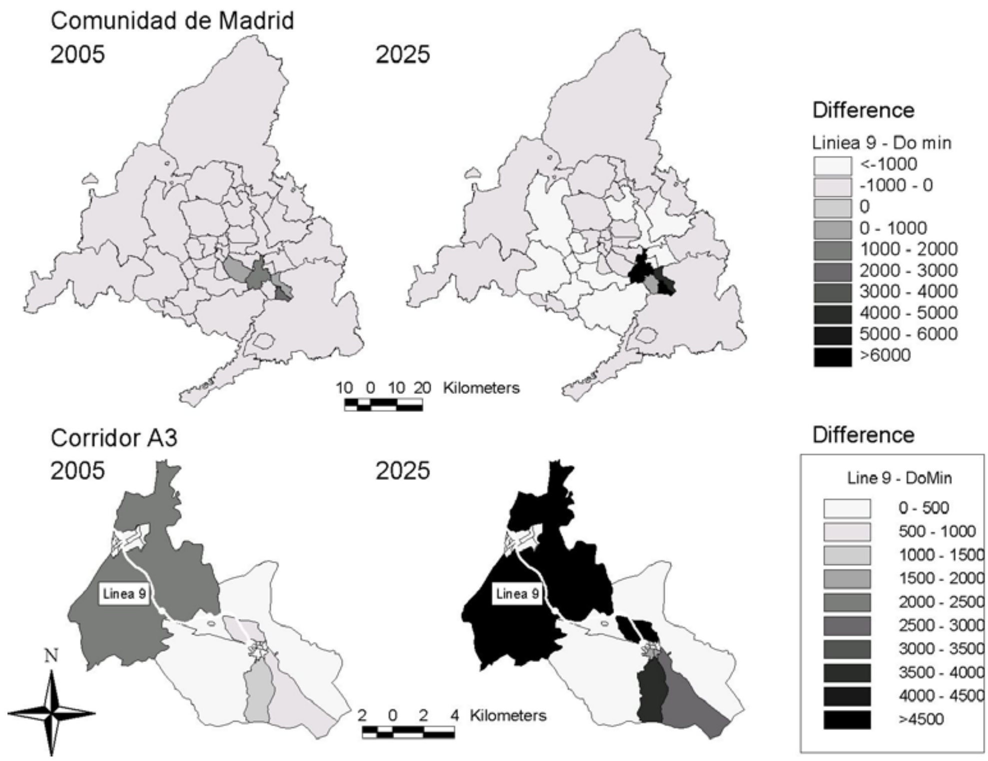

Figure 11: Difference in the number of residents by zone between the scenarios metro line extension and do minimum

Accessibility is measured as the number of working places which can be reached within a weighted time. The difference in accessibility by public transport between the scenarios „line 9“ and „do minimum“ is shown in Figure 12. Of course the metro line extension increases the public transport accessibility of the corridor significantly.

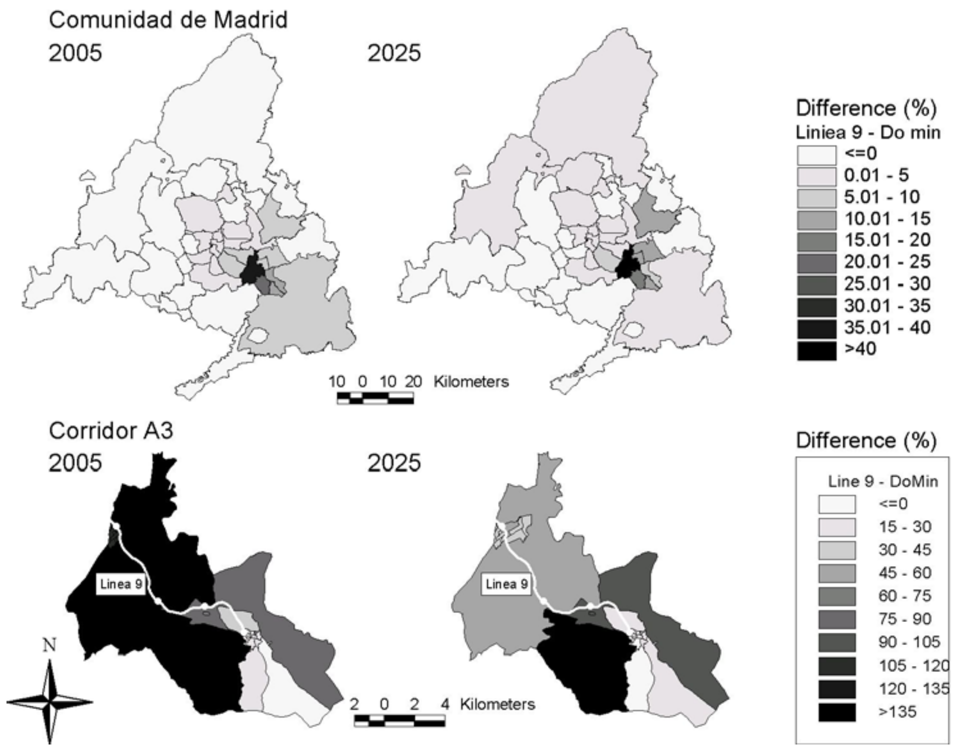

Figure 12: Relative change in the accessibility of working places by public transport between the scenario metro line extension and do minimum

6.3 Bus lanes

The total number of trips is growing in both scenarios due to the overall growth of population. As a result of the bus travel time reduction during peak period the number of public transport users increases significantly compared with the “Do Minimum” scenario. Due to the additional effect of the road capacity reduction the increases are higher in the scenario “Replace Car Lanes”. The situation for the inter peak period and 24 hours is more complex. No travel time savings for bus users occur during the inter peak period. But as MARS is based on the assumption of constant travel time budgets, the time savings from the peak period will be partially spent during the inter peak period. Therefore the total number of trips in off peak increases. In the scenario "Replace Car Lanes" car trips are reduced due to the effect of the reduced road capacity.

In the short run the bus lanes increase the modal share of public transport significantly. In the long run the modal share of public transport goes back to about the initial value. This behaviour coincides with the observations in the aftermath of the installation of the bus/HOV system on the A6 (Monzón, et al. 2003). Nevertheless it remains significantly higher than in the scenario "Do Minimum". The scenario "Replace Car Lanes" significantly decreases NOX and VOC emissions, while the scenario "New Lanes" only has significant effect on VOC emissions (Figure 13).

Both bus lane scenarios reduce CO2-emissions (Figure 14 and Figure 15). But the relative amount is very small: about -0.3% for the scenario "New Lanes" and about -0.5% for the scenario "Replace Car Lanes". Even these small reductions are in danger of being lost in the long term. Especially in the scenario "New Lanes" the additional road capacity is filled up again and CO2-emissions are above the "Do Minimum" levels in the years 2023 and 2024. The instrument "bus lanes" is by far not sufficient to achieve the overall CO2-emission targets.

The bus lanes also affect land use. On the one hand directly due to land consumed by additional highway lanes, on the other hand indirectly due to changed location choices. Figure 16 illustrates this with the difference in the number of residents by zone. Accessibility is the link between transport and location decisions. In the scenario "New Lanes" highways are less congested at least in the short term. In combination with changes in rent and land price this increases the relative attractiveness of the zones in the "Corona Regional". Population therefore increases in these zones in the scenario "New Lanes". This is not the case in the scenario "Replace Car Lanes" and therefore the outermost districts loose population. Nevertheless the pattern of land use changes caused by the bus lane system is not very clear. The location decisions are determined by relative differences between zones rather than absolute changes. Therefore it is possible that one zone with bus lane connection looses population while another one gains population. A more detailed future analysis is needed to clarify this issue. One reason for the unclear picture might be that the bus lanes are quite evenly distributed around the city centre.

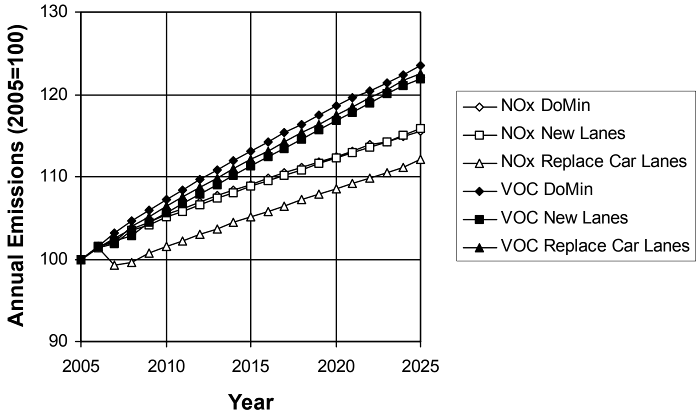

Figure 13: Annual local emissions by scenario (2005 = 100)

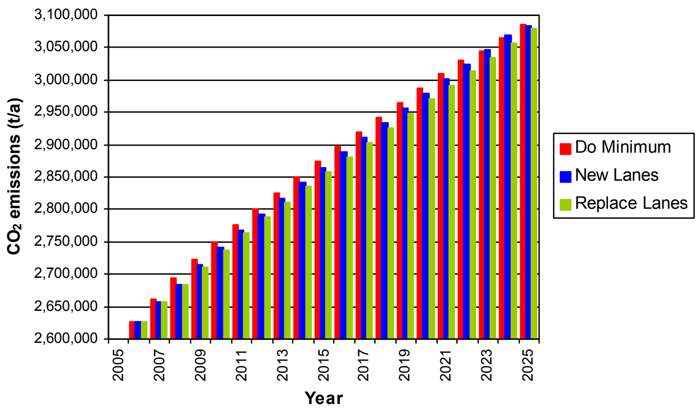

Figure 14: Yearly CO2-emissions by scenario

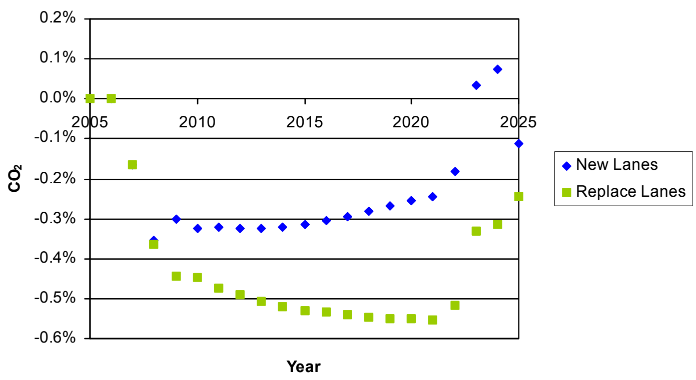

Figure 15: Percentage change of CO2-emissions relative to "Do Minimum"

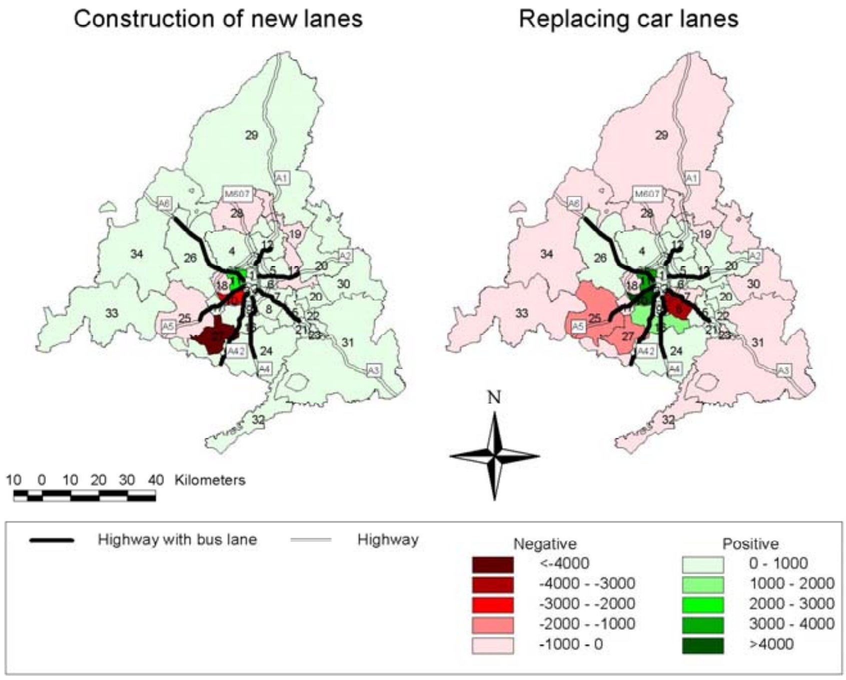

Figure 16: Difference in the number of residents per zone scenario – do minimum

Accessibility changes as expected (Figure 17). Accessibility by public transport increases in both bus lane scenarios. The increase is highest in the bus lane corridors. In the scenario "New Lanes" accessibility by car increases in the whole study area. The increase is highest in the bus lane corridors. In the scenario "Replace Car Lanes" accessibility by car decreases in the bus lane corridors where road capacity for cars is reduced. Due to the overall reduction in car trips it increases in the other zones.

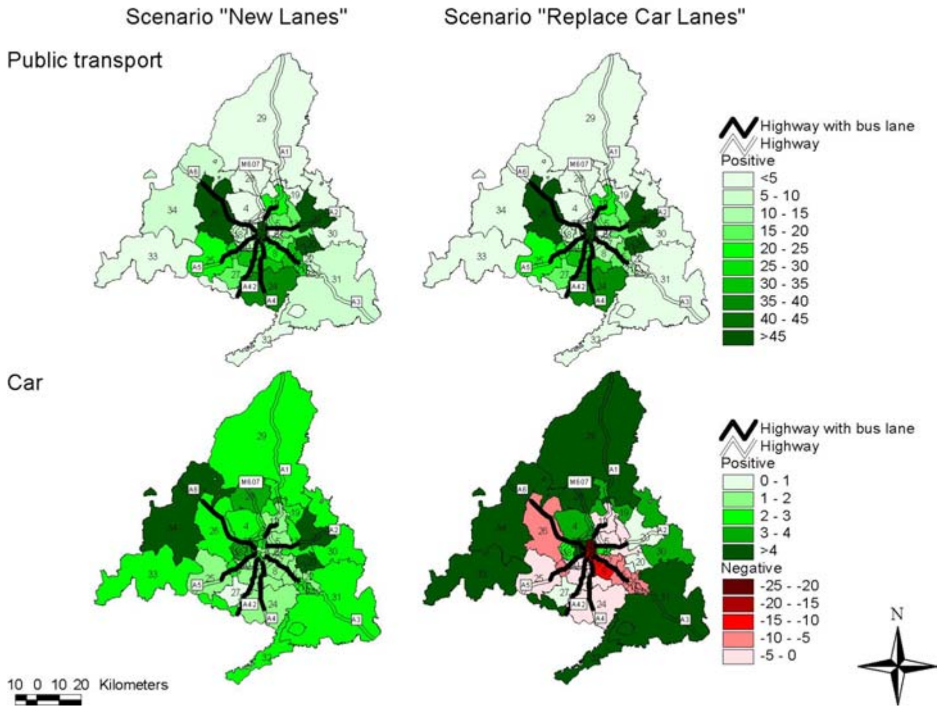

Figure 17: Percentage change of accessibility of workplaces in the year 2025 relative to the scenario "Do Minimum"

7 CONCLUSIONS

7.1 General

The dynamic transport and land use interaction model MARS was employed to assess the effects of two transport infrastructure projects against the overall objective of sustainability: the extension of the metro line number 9 in the southeast of the city of Madrid and a proposal to install bus lanes on all radial highways leading into the city of Madrid.

7.2 Outlook

The work presented here raises several issues for additional future research. Even quite big transport infrastructure projects like the extension of the metro line number 9 have rather limited overall effects for a huge region like Madrid. (Vieira 2005) therefore proposes a hierarchical approach to assess transport and land use projects. This approach will make use of simulation models on different spatial and functional levels. As a starting point (Vieira 2005) has linked the strategic model MARS with a detailed transport demand model of the corridor A3. In ongoing and future research projects the model MARS will be linked on the one hand to detailed assignment models and on the other hand to macro-economic models like ASTRA or POLES (Eijkelenbergh, et al. 2004).

Currently the possibilities to represent public transport infrastructure projects are limited. E.g. in the current version it is not possible to combine the instruments “metro line extension” and “bus lanes”. Adaptations within an ongoing research project (Emberger, et al. 2005) offer an opportunity to improve the model with respect to this issue.

Additionally there were some shortcomings concerning data availability. There was no information available about the positions of entry and exit points or bus stops within the proposed bus lanes. Therefore all zones crossed by bus lanes benefit to a certain extent. If there will be no entry/exit point or bus stop in the zone this will definitely not be true. Furthermore assessment results are highly sensitive to investment costs. These costs should be examined in more detail to get a clearer picture.

Finally the land use response pattern of the bus lane scenarios is a bit unclear. It would be useful to analyse the causes for the location choices in more detail. To gain better insight it is suggested to model and analyse each radial highway separately and in combination.

7.3 Assessment results

7.3.1 Metro line extension

The metro line extension creates a small welfare surplus. Public transport users receive the highest benefits in form of time savings. These represent about 2/3 of all benefits generated. Public transport operators and the government are the ones who finance the policy. They bear about 60% of the total costs while receiving just about 7% of the benefits. Concerning land use, property owners gain profit while property users have to bear higher costs than in the do minimum scenario. The environmental benefits account for about 5% of the total benefits. The attractiveness of the corridor A3 clearly benefits from the expansion of the metro line number 9. Accessibility by public transport improves significantly. More investors are attracted to develop living space and more residents are attracted than without the metro line. The results for environmental effects in form of NOX and VOC emissions are a bit ambiguous. Although they decrease in the short term, they increase in the long term. The main reason is the growth in population mentioned above. This demonstrates that the use of a land use and transport interaction model is essential when assessing sustainability.

7.3.2 Bus lanes

The welfare surplus created by the bus lane scenarios is higher than that of the metro line extension. As the bus lane scenarios cover all corridors this is in line with expectations. About 70% of the benefits are created by time savings. Again public transport operators and the government are financing the surplus. They bear about 30% (“Replace Car Lanes”) to 80% (“New Lanes”) of all costs. The reduction of greenhouse gas emissions is very small for both the “New Lanes” and “Replace Car Lanes” scenario. They make up less than 1% of the benefits. The total external costs of the scenario “New Lanes” are even negative due to increased accident costs caused by higher car speed. Accessibility by public transport improves significantly within the bus lane corridors. The bus lanes increase modal share of public transport in the short term but it goes back to initial values in the long term. Which nevertheless is still higher than in the scenario “Do Minimum”. The scenario “Replace Car Lanes” significantly decreases NOX and VOC emissions, while the scenario “New Lanes” only has significant effect on VOC emissions. The increase in accidents caused by higher car speeds offsets these improvements in the category external costs. The effects on land use are a bit unclear and need more investigation (see 7.2 Outlook). The option “Replace Car Lanes” has to be favoured from a sustainability point of view.

7.3.3 Summary

Finally it can be concluded that all three investments tested create a surplus in welfare. Nevertheless they require higher public spending than in “Do Minimum”. The positive results are in any case driven by the time savings of public transport users. The use of time savings is not undisputed (Emberger, et al. 2004). Without time savings all results would be negative. Furthermore the contribution to the overall objective of sustainability is rather small. The potential of the investments to reduce negative environmental impacts is limited. As a general conclusion it can be stated that no single project will be able to achieve the goal of a sustainable urban region. A comprehensive strategy including other complementary instruments like pricing is necessary to achieve the objective of sustainability.

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