RELATIONSHIP BETWEEN HUMAN ACTIVITIES DENSITIES AND TRANSPORTATION NETWORKS WITHIN THE SUBURBS OF LARGE AND MEDIUM CITIES

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ABSTRACT

The suburbs in mega-cities represent particular problems for sustainable mobility; more than three quarters of inhabitants are leaving in suburbs with very poor accessibility to mass public transport; more over the quest for a job, or the quest for a better job shows that commuters are facing very long trips.

To understand those problems it was necessary to do a review of land use planning and transportation networks in the suburbs of mega-cities; we did some case studies which provided figures for the metropolitan areas on three continents, namely North America, Europe and Asia; observed cities were divided and analyzed with respect to their size and stage of development.

The objective of this investigation was to gather relevant key findings and identified best practices in order to provide convenient guidance to road administrations.

The analysis mainly focussed on the relationship between density (population and employment), transportation networks and mobility data. The accessibility to public transportation in the periphery of urban areas was a key question.

The most important learning of this work is that there is no perfect land planning in our case studies; therefore there are millions of people leaving in suburbs with lower population density and there is no perfect "sustainable transport policy" for them.

But this comparison enabled to identify a number of key findings such the expansion of commuting areas, and to highlight good practices.

As a conclusion it appears that we should put "the commuter at the centre of policies" and provide a range of coordinated actions in favour of public transport by road in areas with low population densities.

It is also recommended that data collection programmes continue in order to provide fact-based support to local authorities to help in decision making related to transportation infrastructure.

1. INTRODUCTORY REMARKS

This study has been produced by members of the sub group 2 of the PIARC technical committee 3 dedicated to "Land use planning and road transport" in the framework of the 2008-2011 work programme and is based on nine case studies (Table 1).

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Table 1 - Case studies

Metropolitan area	**Great cities (over 5 million people)**	**Middle-size cities**
Low growth rate cities	Tokyo Paris Madrid Toronto	Stockholm Bucharest Helsinki
High growth rate cities	Mexico	Chihuahua

This paper will present some key findings based on data comparative analysis mainly for Tokyo, Paris, Madrid and Toronto metropolitan regions concerning:

- land use,
- transportation network,
- mobility,
- accessibility to mass transit networks,
- expansion of commuting areas.

Finally we will present some best practices.

Please note that the issues covered below should be analysed in greater detail, and that the comments and recommendations are those of the authors only.

2. KEY FINDINGS BASED ON DATA COMPARATIVE ANALYSIS FOR LAND USE,

For each agglomeration the figures have been gathered according to three zones:

- the core city,
- the inner suburbs,
- the outer suburbs.

These areas have been defined according to the administrative boundaries of each agglomeration. Main figures (for great cities with low growth rate) as concerning land use are given in Table 2.

Table 2 - Population and employment densities

Region		Radius (km)	Area (km?	Number of local authorities	Population & employment		Population & employment density	Ratio employment/ pop. (jobs offered / inhabitant)
					Residents (1 000)	Jobs (1 000)	Resident + job density ((pers.+jobs)/km?	
Tokyo	Central 7 wards	5	100	7	1 275	3 465	47 505	2,7
	Suburb	14	584	19	7 643	3 685	19 402	0,5
	Periphery	70	15 050	249	27 166	10 384	2 495	0,4
Total Tokyo Met Area		70	15 734	275	36 084	17 533	3 408	0,5
Paris	Paris itself	5	87	20	2 125	1 656	43 463	0,8
2001	Inner Suburbs	15	657	123	4 039	1 741	8 798	0,4
	Outer Suburbs	60	11 250	1 157	4 788	1 645	572	0,3
Total Paris Region (1999)		60	11 994	1 300	10 952	5 043	1 334	0,5
Madrid	Almendra Central	3	42		999	960	46 650	1,0
2004	Perifieria Urbana	13	564	1	2 100	816	5 167	0,4
	Corona Metropolitana+Regional	50	7 422	178	2 705	988	498	0,4
Total Madrid Region		50	8 029	179	5 805	2 763	1 067	0,5
Toronto	Inner city	14	630	1	2 503	1 242	5 944	0,5
	suburbs	51	7 612	27	3 557	1 861	712	0,5
Total Toronto Region		51	8 242	28	6 060	3 103	1 112	0,5

Although Tokyo Paris and Madrid have very different sizes (respectively 36, 11 and 6 million inhabitants) the key findings are similar:

1. Over 80% of the population live outside the core city (and 95% for the Tokyo region).
2. Employment distribution is also very spread out; only Tokyo succeeded in maintaining an employment to population ratio higher in the centre, however, that point needs to be put into perspective with the absolute values (3 million jobs in the centre versus 14 million in the suburbs).
3. Human activity densities (work + population) are similar in the 3 core cities and they fall dramatically towards the suburbs: activity densities are divided by a 100 factor within Paris and Madrid outer suburbs and by a 20 factor within Tokyo outer suburbs.

These are three effects of urban sprawl but also of the spread of activities; modal split will depend on those effects.

Regarding Toronto witch reflect the general pattern of North American cities, the metropolitan region is split in two areas, namely Toronto and the suburbs.
But we can compare it to Madrid when gathering figures from the areas “Almendra Central” and “Perifieria Urbana” in Madrid. The densities of “human activity” are about 8 000 persons and jobs/km² under 15 km, which is comparable to the 6 000 persons and jobs/km² in Toronto.
Regarding the suburbs of Toronto region and the outer suburbs of Madrid (Corona Metropolitana + Regional), densities of “human activity” are also comparable with values between 500 and 700 persons and jobs/km².

Urban sprawl over a century was studied in Paris and it can be summarized by few figures:

- in 1900 the region had 3 million people in Paris and 2 million in the suburbs
- one century later there are 2 million people in Paris and 9,7 million in the suburbs

It appears that it is generally very difficult to struggle against urban sprawl. This is due to human desire to have more space (larger flats, detached houses…)

We should also consider the number of local authorities (from about 30 to 1300): their impact on planning decisions should need a specific analyse.

3. KEY FINDINGS CONCERNING DATA COMPARATIVE ANALYSIS FOR TRANSPORTATION NETWORK

Table 3 gives transportation networks density for the three areas:

Table 3 - Transportation network densities

Region		Area (km?	Resident + job density ((pers.+jobs)/km?	Networks - Densities		
				Density of expressways (km/km?	All railway modes - Density of lines (km/km?	All railway modes - Density of stations (stations / km?
Tokyo	Central 7 wards	100	47 505	0,57	3,15	2,86
	Suburb	584	19 402	0,29	1,02	0,78
	Periphery	15 050	2 495	0,04	0,19	0,08
	Total Tokyo Met Area	15 734	3 408	0,05	0,24	0,13
Paris	Paris itself	87	43 463	0,41	3,14	3,37
2010	Inner Suburbs	657	8 798	0,26	0,61	0,32
	Outer Suburbs	11 250	572	0,05	0,09	0,03
	Total Paris Region	11 994	1 334	0,07	0,14	0,07
Madrid	Almendra Central	42	46 650	0,77	2,93	2,24
2008	Perifieria Urbana	564	5 167	0,11	0,39	0,24
	Corona Metropolitana+Regional	7 422	498	0,11	0,05	0,02
	Total Madrid Region	8 029	1 067	0,12	0,09	0,05

Mass transit networks (metro, railways) present interesting similarities:

1. The density of railway stations is practically the same in the three core cities (3 stations per km²); any location in these areas is within 10 minutes walking distance from a station.
2. The number of railway stations is divided by a 10 factor in inner suburbs and by a 100 factor in outer suburbs in Paris and Madrid regions and respectively by 4 and 35 in Tokyo region. It is obvious that access to mass transit deteriorates significantly with a move to the suburbs; regarding this latter aspect, more details are presented in the Paris case study.

3. Expressways densities are better balanced;
   Data concerning local roads should be compared also and this analysis has been carried out for Paris only.

4. In Tokyo, Paris and Madrid larges sections of the expressway network have been built underground.
   In Madrid, around 43 km of tunnels (the "Calle M-30" project) have been put into operation under the first ring road; on a total of around 70 km of tunnels within the metropolitan region. In Tokyo, important sections of the ring roads have also been constructed underground. The outer suburb of Paris presents an innovative solution for road infrastructures, the Duplex A86.
   The

   Table **4** below summarizes figures for tunnels within Tokyo, Paris and Madrid metropolitan areas:

Table 4 - Road built underground in Tokyo, Paris and Madrid

City	Area	Number (length > 1 km)	Length (km)
Tokyo	Core city	18	34,0
	Suburbs	10	17,0
	Total	28	51,0
Paris	Core city	2	4,9
	Suburbs	10	31,0
	Total	12	35,9
Madrid	Core city	10	58,5
	Suburbs	4	10,6
	Total	14	69,1

N. B.: One needs to consider the figures from Madrid with caution because double tunnels are counted twice. The figures for inner Madrid are explained by addition of several tunnels located along the Calle M-30 (43, 5 km in total).

4. DATA COMPARATIVE ANALYSIS FOR MOBILITY, AND KEY FINDINGS

Gathered figures about mobility statistics are summarized in the Table 5 below:

Table 5 - Mobility statistics for Tokyo, Paris, Madrid and Helsinki

		Travelled distances		Number of daily trips				
Region	Mode	pass.km/day	Modal split (%)	1 000 000 trips / day	Modal split (%)	Modal split motorized modes (%)	Average distance (km / trip)	Average trip time (minutes / trip)
Tokyo Metro Region	Railway (train, tram, metro)			25,0	30%	47%		63
	Bus			2,2	3%	4%		38
	Passenger car (+ taxi)			25,9	31%	49%		28
	Non motorized			29,9	36%			15
Paris Metro Region	Railway (train, tram, metro)	50 653 745	31%	4,6	14%	21%	11,0	50
	Bus	7 840 662	5%	2,2	7%	10%	3,6	33
	Passenger car (+ taxi)	99 532 069	60%	15,4	47%	70%	6,5	22
	Non motorized	7 303 993	4%	10,7	33%		0,7	14
Madrid Metro Region	Railway (train, tram, metro)	32 240 000	27%	2,6	18%	27%	12,4	44
	Bus	19 300 000	16%	1,9	13%	19%	10,2	
	Passenger car (+ taxi)	64 550 000	53%	5,3	37%	54%	12,2	25
	Non motorized	4 800 000	4%	4,7	32%		1,0	16
Helsinki Metro Region	Railway (train, tram, metro) Bus	9 359 700	29%	0,9	23%	33%	10,4	36
	Passenger car (+ taxi)	20 505 600	64%	1,8	45%	67%	11,5	22
	Non motorized	2 179 000	7%	1,3	32%		1,7	18

One can observe the following findings:

1. in Paris and Madrid regions non-motorised modes represent the third of all trips and only 4% of the total travelled distances,
2. Regarding motorized modes, average distances are generally high (from 3.6 to 12.4 km as the crow flies) and average trip times are high too (from 22 to 28 minutes by car and 44 to 63 minutes for mass transit).
3. Roads (bus + passenger car) represent :
   a. 34% of the number of trips in Tokyo 50% in Madrid and 54% in Paris
   b. two thirds of the travelled distances in Paris and Madrid
4. Despite similarities between the three cities in terms of land use and mass transit networks densities, Tokyo gets a remarkable modal split in favour of mass transit. The relative concentration of employment in the core is not sufficient to explain this

gap with others cities; the networks pattern would not explain this neither. A finer comparison of land use enables to identify reasons of such differences in mobility statistics. Figure 1 below show population densities for both Tokyo (left) and Paris (right) regions with the same scale:

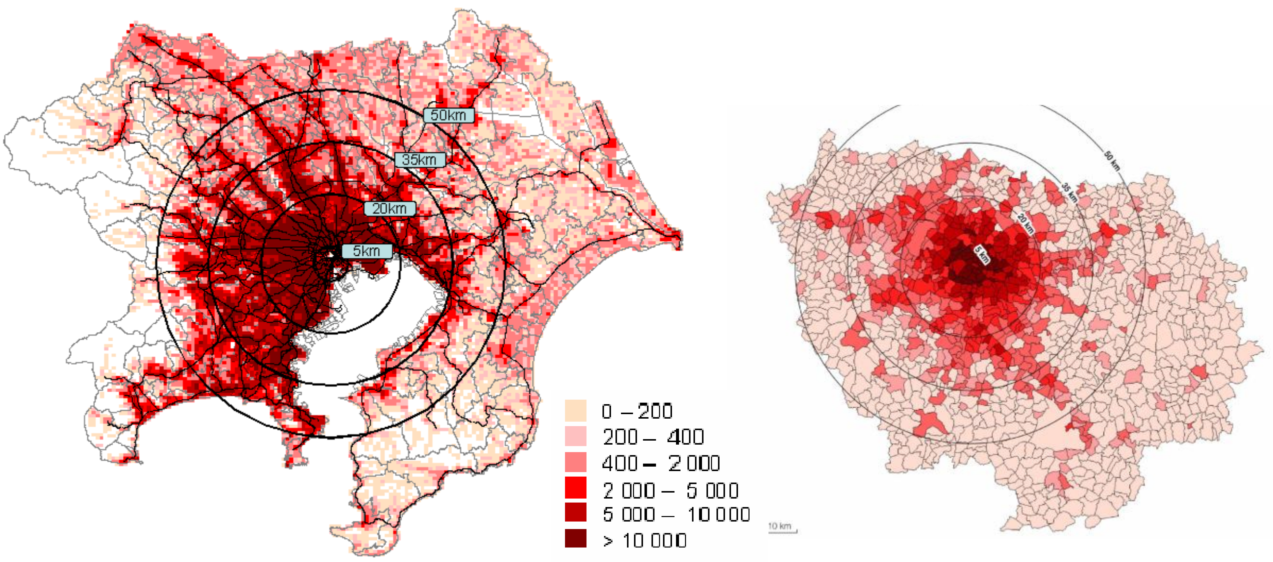

Figure 1 - population densities in Tokyo and Paris

In Tokyo the pattern of land use densities follows the pattern of main mass transit networks: Tokyo is an interesting case of coordinated planning between rail mass transit networks and urban development. There will be a presentation on that key finding by Dr. Yajima Takashi.

5. Madrid is characterized by use of buses and coaches twice as high as for Paris without deteriorating the modal share of mass transit. This point is developed in the case study.

5. ACCESSIBILITY TO RAPID MASS TRANSIT NETWORKS

We have seen that the mass transit networks can not follow the urban sprawl and that the densities of stations are divided by a factor of 30 to 100 between the core city and the outer suburbs; as a result the accessibility to the mass transit network falls dramatically and we have check it on some cities.

5.1. Example 1 : railway network accessibility in Stockholm region

About 30% of the population in the Stockholm region lives within 400 metres from railway station. However there are great regional differences in accessibility. The accessibility rapidly decreases with increasing distance from the city centre. The population in the central and densest parts of the region is well-served with public transport, while the population in the outer parts of the region has a deficit.

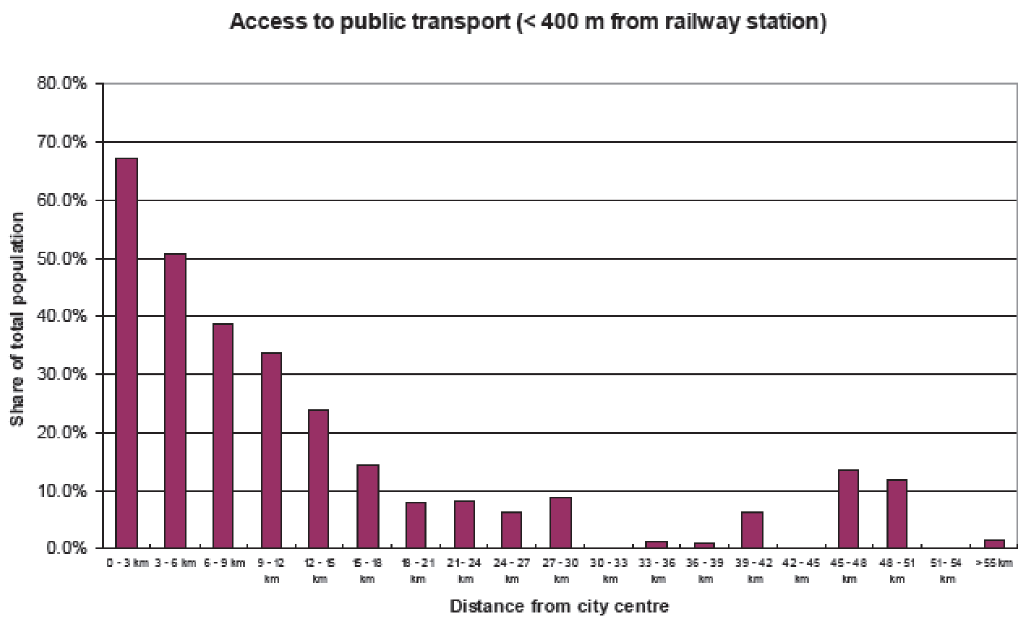

Figure 2 - Access to public transport in Stockholm region.

Figure 2 shows that accessibility rate to railway network falls dramatically between the inner city and the suburbs. Almost 70% of the population within 3 km from the city centre lives no further away than 400 metres from a station, while at a distance of about 20 km, this has dropped to under 10%.

5.2. Example 2 : railway network accessibility in Paris region

Similar analysis was done for Paris and Table 6 shows the number of people who have an access within 10 minutes walking to a railway or metro station:

Table 6 - accessibility to mass transit stations in Paris

Radius 3 km	Paris	5 to 8	8 to 11	11 to 14	14 to 17	17 to 20	20 to 23	23 to 26	Balance 26 to 50	Total
Area (km²)	87	106	179	235	319	398	306	459	4 686	6 774
Population (1 000)	2 125	1 204	1 377	1 234	1 026	705	500	497	1 826	10 494
Population with an access to the network	2125	369	323	240	106	45	76	75	222	3581
	100%	31%	23%	19%	10%	6%	15%	15%	12%	34%
Pattern of the network	Dense	Essentially radial								

It appears that:

1. In the city core (Paris itself) 2 million people live ay less than 10 minutes of a railway or metro station
2. In the suburbs only about 1.5 million people (on a total of 9.4) live close to a station; as a consequence about 8 million people do not have a good accessibility to mass transit networks
3. In the suburbs the pattern of the mass transit networks is essentially radial witch means that it gives a very poor service for "suburb to suburb" trips; how ever there is a project of a circular line to give an answer to that question and S Coutel will describe it.

6. EXPANSION OF COMMUTING AREAS

6.1. Example 1 : expansion of the Helsinki commuting area and increase in trip distances

In Helsinki, the commuting area has steadily expanded and now covers an area with a radius of almost 100 km. As a result the home to work journeys distances from the suburbs over 20km represented less than 35% of journeys in 1980 whereas they represent more than 45% in 2005. It is these home-to-work journeys that are used in planning for the capacity of transport infrastructure (Figure 3).

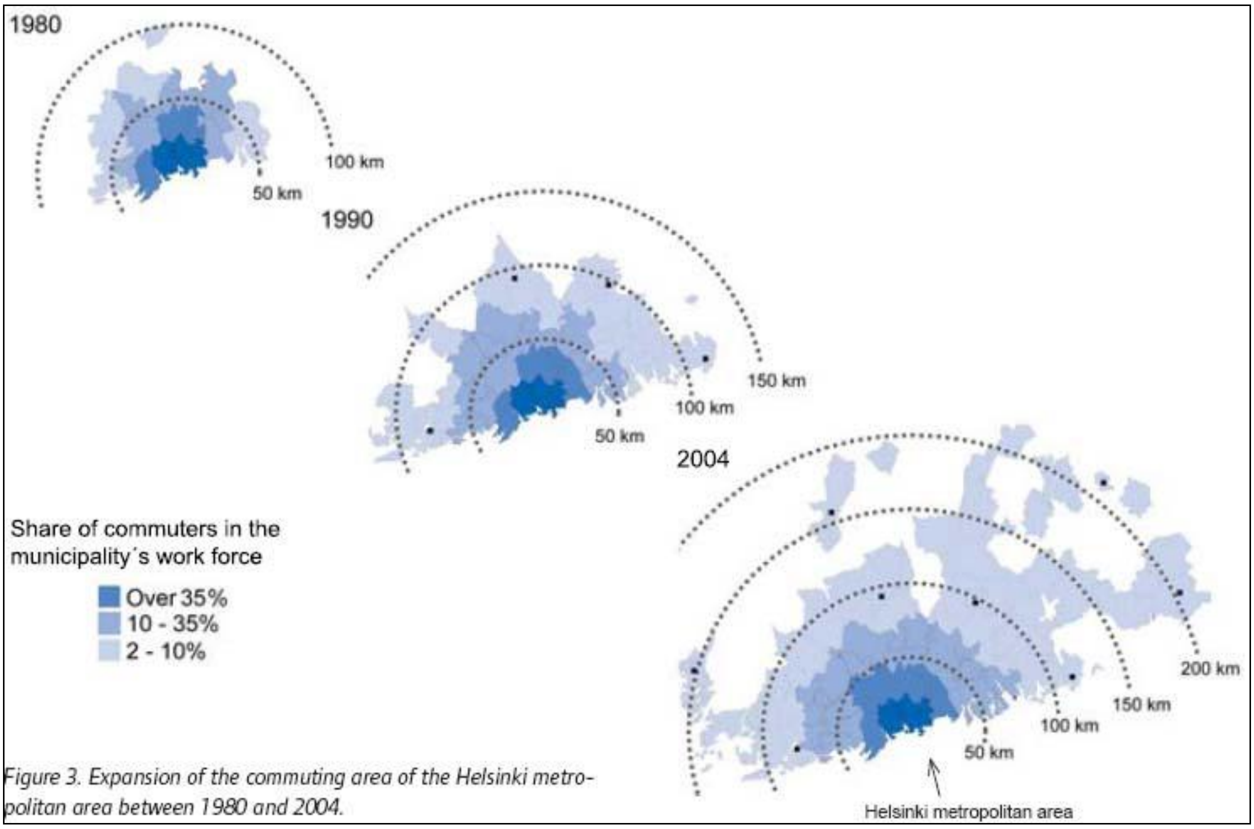

Figure 3 - Expansion of the commuting area of Helsinki metropolitan region between 1980 and 2004.

As most of the jobs are located in the inner areas of the Helsinki Region, work trips are considerably longer in the outer areas of the region.

The expansion of the urban area is shown by the fact that the length of the work trips is continuously increasing in the outer areas, as the corresponding figures in the inner area (the Metropolitan Area) have stayed steady during the last three decades.

It is important to notice that during the 1980s, and also in the 1990s, the share of short work trips (less than 5 km) was higher in the outer areas than in the Metropolitan Area. This is explained by the fact that a larger share of the population lived in small communities and they worked in the same community. At the same time the share of population making long work trips (over 5 km and particularly over 20 km) has grown steadily. These people are commuters, or “urban sprawlers”, moving out of the Metropolitan Area but still working there.

6.2. Example 2 : expansion of the Paris commuting area and increase in trip distances

In Paris the average length of the trips is measured through surveys witch are done every 7 to 10 years between. Table 7 shows the average length of the trips for commuters and its expansion between 1976 and 2001.

Table 7 - expansion of commuting trips in Paris

Commuters (all modes)	1976	1983	1991	2001	2001/1976
Number of trips per day (x 1000)	6 714	6 327	6 323	6 849	2%
Total distance (straith line 1000 km)	44 562	46 958	54 953	66 397	49%
Average distance (straith line in km)	6,6	7,4	8,7	9,7	46%

Those facts seems to be an important key finding; it appears that commuters are ready to get the “right job” very far from there home even if existing jobs are close from there home. Of course the distance of commuters trips increases with the size of cities.
It is difficult to struggle against the increase of trips distances as well. This phenomenon reflects first of all the need for a job but also the need for freedom (freedom of choice of the type of job and of the employer).
In other words the development of non-motorised modes is necessary for the local mobility but it is not able to address the needs of the majority of trips and in particular the commuters needs.

7. BEST PRACTICES TO IMPROVE ROAD EFFICIENCY IN THE SUBURBS

Based on the observations of our case studies, this chapter presents a set of best practices in terms of land use planning, optimized road operations, other transportation solutions and mobility policies.

7.1. A coordination strategy between Rail and Suburban development in the Tokyo metropolitan region (TMR)

The coordinated rail and suburban development strategy consists of:
(1) Rights to suburban rail operations.
(2) Purchase of land tenure for development by private rail companies.
(3) Rail extension and/or new station coupled with development.
(4) Choice of development pattern, creating bi-directional transportation demand.

This strategy has worked well as an urban development and transportation policy to accommodate Tokyo’s increasing urban population and to provide and maintain efficient rail service avoiding over-dependence on private car.

Moreover, the strategy has worked well as a business model. Rail companies can rely on non-rail revenue to expand their revenue base and contribute to the sound financial management of their rail corridors by providing funding for rail investment from the real estate sector. The ratio of non-rail revenue to overall revenue ranges between 30 to 50% for the nine major private rail companies in the TMR

As a result, the TMR has a radial and circular railway network consisting of 3,700 km of lines with 75% of the population living within 1.5km from a station. But according to a recent evaluation, the strategy has failed to cover all urbanized areas: local road are required to support low-density areas.

7.2. Organization of bus networks in Madrid region

In the Madrid metropolitan area, a network of 44 bus routes is organized to collect passengers in the northwestern suburb of the city where they are connected to a railway/metro station through eversible lanes reserved for high-occupancy vehicles.

The project was developed 15 years ago in response to the population growth along the A-6 corridor and severe environmental barriers to development. An urgent solution was required to meet the growing transportation demands in this suburban area. This solution involved the construction of 16 km of HOV-bus lanes located in the centre median of the A-6 motorway. In the outer suburb, the first 12 km two-lane section is reserved for buses, car-pooling and motorbikes. Approaching Madrid, the last 4 km are reserved exclusively for buses.

At peak periods, with a flow of 200 buses per hour, up to 8,000 riders can use the system per hour providing an efficient mobility solution for 110,000 commuters per day. The reasons this system has been so effective are:

1. a network of 44 bus routes covering the majority of the northwestern suburb;
2. a free-flowing transportation infrastructure is provided in a congested corridor during rush hours;
3. an efficient interconnection of bus routes with Madrid's extensive metro system.

7.3. Underground solution for environmentally integration of road infrastructures

In Tokyo, Paris and Madrid larges sections of the expressway network have been built underground. In Madrid, around 43 km of tunnels (the "Calle M-30" project) have been put into operation under the first ring road; on a total of around 70 km of tunnels within the metropolitan region. In Tokyo, important sections of the ring roads have also been constructed underground. An innovative tunnel in Paris is presented in Special Session 4 dealing with large cities: integration of the surface transport modes.

Those solutions are generally used in areas where there is very high expectations regarding environmental protection.

7.4. HOV lanes in Ontario and HOT lanes (congestion charging) in North America

HOV lanes are a commonly used tool to optimize capacity of road infrastructures within North America. Highway agencies and toll authorities across the United States operate over 2,500 HOV lane miles with approximately 2,500 more HOV lane-miles planned over the next thirty years.

In the Greater Toronto area, peak hour traffic on the 400-series highways is becoming increasingly congested. In an effort to manage congestion and encourage more efficient use of infrastructure, the Ontario Ministry of Transportation has introduced High Occupancy Vehicle (HOV) lanes on some of its highways and roads (e.g. on Highway 404 in Toronto) .

The Government of Ontario has developed an ambitious plan to add over 450 km of new HOV lanes on 400-series highways in the Greater Golden Horseshoe (centred around the Greater Toronto Area) by 2031. This project includes some of the most heavily-congested highways in the province. The planning is motivated by the fact that an HOV lane full of buses and carpools moves many more people than a general traffic lane.

As is the case with other jurisdictions, the financing of transportation infrastructure is a challenge. Road tolls and other alternative financing mechanisms are slowly emerging to the forefront for public and political debate. Such options may be discussed by the Province of Ontario and local governments as the June 2013 deadline for the Regional Transportation Plan for the Greater Toronto and Hamilton Area, *The Big Move*, to finalize its financial strategy approaches.

In the early part of this century (2000s), in the United States, highway lanes constructed in the 1970s formerly reserved for vehicles with more than three people onboard (high-occupancy vehicles or HOVs) were transformed into free-flowing lanes open to all types of vehicles (high-occupancy tolls or HOTs). The concept evolved in response to the frustration of motorists blocked in the neighbouring (non-HOV) congested lanes, and in order to optimise the potential of road transportation infrastructure as a whole. Free flow in these lanes is guaranteed by applying a toll to vehicles with less than three occupants with a varying fee based on lane usage. This operating system offers good traffic conditions for high added-value trips (buses, emergency services, car-pooling, etc.), freedom of choice for motorists with time demands, as well as an additional resource for public finances.

7.5. Parking policies in Helsinki

Restrictive and selective on-street parking policy in the Inner City, including residential and corporate parking, was decided in conjunction with a Master Plan in the early 1970's. The policy has remained practically the same since then. The share of public transport (including buses) to the city centre is high, nearly 70 % during peak hour and 60% during the whole day. Traffic volume to the centre has increased only slightly during the last 20 years while traffic volumes on other cordon lines have increased substantially.
New commercial land-use is mainly directed to suburban centres according to the approved land-use policy. This policy in conjunction with restrictive and selective on-street parking policy in the inner city combined with large private underground parking facilities does not seem to have weakened the competitiveness of the city centre.

8. CONCLUSION AND OUTLOOK

While policies in developed countries focus on the environmental aspect of mobility, the World Bank gave in 1996 the following definition of a sustainable transport policy:
“To be effective, transport policy must satisfy three main requirements. First, it must ensure that a continuing capability exists to support an improved material standard of living. This corresponds to the concept of economic and financial sustainability. Second, it must generate the greatest possible improvement in the general quality of life, not merely an increase in traded goods. This relates to the concept of environmental and ecological sustainability. Third, the benefits that transport produces must be shared equitably by all sections of the community. This we term social sustainability”.

Those case studies allowed a detailed analysis of the relationship between human activity densities (population and employment), transportation networks and mobility data; we should analyse our findings in relation with that definition.

The most important learning of this work is that there is no perfect land planning in our nine case studies; therefore there are millions of people leaving in suburbs with lower population density and there is no perfect “sustainable transport policy” for them.

But this comparison enabled to identify a number of key findings such the expansion of commuting areas, and to highlight good practices; it appears that we should put "the commuter at the centre of policies" and provide a range of coordinated actions in favour of public transport; it could be for example interesting to coordinate an organisation of a bus network with efficient interconnections to the mass rapid networks like in Madrid, with adequate road operating systems like in the HOT case.

This analysis would not have been possible without the existence of reliable statistical data. It is therefore recommended that data collection programmes continue in order to provide fact-based support to local authorities to help in decision making related to transportation infrastructure.

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