DENSITY AND MIXED LAND USE FOR SUSTAINABLE URBAN DEVELOPMENT

Stefano Gori, Roma Tre University, sgori@uniroma3.it

Marialisa Nigro, Roma Tre University, mnigro@uniroma3.it

Marco Petrelli, Roma Tre University, mpetrelli@uniroma3.it

ABSTRACT

In the last years important changes on urban features strongly modified the quantity and the quality of mobility system: the automobile is considered the only transport mode and the use of transit became more and more unused with strong impacts on environment and sustainability.
To develop sustainable urban areas, oriented on transit and on other transport modes such as pedestrian and bicycle, different elements, criteria and policies are analyzed (trips demand concentration, adequate transit network design criteria to improve the "door-to-door" travel times, mixed land use, etc.) and their impact in terms of demand modal split are tested for the case study of the city of Rome. The test results are used for some considerations about the importance of the interaction between land use policy and transportation planning.

Keywords: sustainable mobility, land use, urban transport, public transport

INTRODUCTION

In the last years important changes on urban features strongly modified the quantity and the quality of mobility system: the continuous spread of residences and activities have increased the length of trips and the use of private transport; the usual mobility habits have been changed by more complex behaviours (trip chaining). The automobile is often considered the only transport mode and the use of transit became more and more unused with strong impacts on environment and sustainability. These observations are supported by data from Sinha (2003) related to travel characteristics for 46 cities in the world for the period 1960-1990. During these years, a generalized decrease of the density of urban population is recorded and it is associated to a generalized relevant increase in terms of private vehicle ownership and level of use. Transit ridership presents consistent reductions in many cities with the exception of few cases (Hong Kong, some European and Canadian cities) where the number of travel by transit services increase.

These changes are also due to the results of the evolution of urban areas according to the different stages of development of the transport modes technology: the first stage is known as “urban concentration” with small urban area characterized by high density; the second stage is the “suburbanization” in which the city centre cannot accept further demand of residences and activities and so conurbations start to grow up; the last stage is based on the urban decentralization.

Newman and Kenworthy (1996) describe this trend as the transfer from “pedestrian cities", characterized by a unique compact nucleus, developed until the middle of the XIX century in Europe, to the building of small centres localized along the main railway systems (“transit oriented cities”, Figure 1). Starting from 1940 and up to nowadays, the metropolitan areas are converted into the modern “automobile city", where the dispersion of activities and residences on the territory, the road network that moves further away from a grid structure, the big spaces that separates buildings, all of these make the private vehicle the only possible method of transportation.

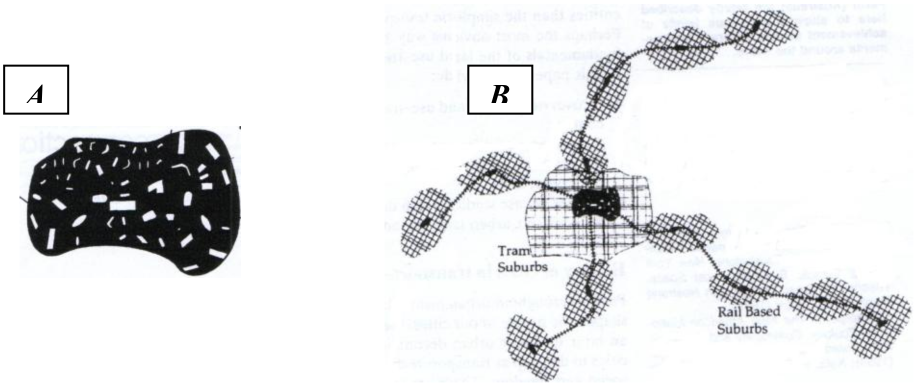

Figure 1 – “Pedestrian city” (A) and “Transit oriented city” (B)

The automobile is one of the reasons of this evolution having the ability of favouring the dispersion of the accumulation points of transport demand over the entire territory. Transport systems alternative to the automobile as transit or pedestrian and cycling mobility take a more and more marginal role in the evolution process of the urban structure and, in the “automobile city" phase, they are considered only after the urban plan has been laid out.

The effects on a spatial, temporal and environmental level are quick to follow and the resulting phenomena of congestion can't find a solution by exclusively recurring to an increase in the infrastructure supply of such transport mode. The construction of a sustainable urban development needs the creation of a sustainable mobility and it is though a possible aim when one can count on public transport. It is enough to realize how the use of a transit service can save an enormous amount in terms of space. It is sufficient to consider that the transport of 50,000 persons in an hour, in a given direction needs a road 175m wide for cars, 35m wide for a bus service, and only 9m wide for a metro system. Moreover, if the transit system is effective and efficient, with the spatial use reduction, there is also a save in time lost due to the streets' congestion (it is estimated that every city inhabitant in Italy loses 88 hours a year stuck in traffic, Cascetta 2005). From the environmental point of view, the whole transport system has an estimated impact on CO_2 emissions of about 29% and the specific car emissions are three times greater than the specific bus emissions and ten times greater than the specific metro emissions (Cascetta, 2005).

This paper is structured in five sections including the introduction; in the second section there is an analysis both of the literature and of remarkable examples of sustainable mobility in the world; the third section shows the impacts on the demand modal split using different elements and criteria to improve the transit system for the case of the city of Rome while the fourth section introduces a detailed analysis about roman urban structure to better understand the results of the previous described section; the fifth and last section contains observations and final considerations about the importance of the interaction between land use policy and transportation planning.

ELEMENTS AND CRITERIA FOR THE DESIGN OF COMPETITIVE PUBLIC TRANSPORT SYSTEM

The automobile has numerous strengths: it is a service with infinite frequency, of immediate access, comfortable and rapid. On the other hand, transit service has a scheduled frequency, not always high, with extra time losses due to access, boarding and sometimes transfers.
Given these issues, if transit system could be the solution to reach a sustainable mobility, it is clear that the objective is to make transit system competitive by comparison with the private transport system.

About the opportunities provided by the public transport systems to develop a sustainable mobility, Bernick and Cervero (1997) and Cervero (1998) show, introducing the concept of the "transit metropolis", examples of transit services that provide respectable alternatives to car travel. This is the case of Zurich and Melbourne, where the city is formed by a unique central and compact business area or Stockholm and Copenhagen, where new urban areas have appeared concentrated along the railway stations so connected with the historic central nucleus (see “transit oriented cities" of Newman and Kenworthy-1996, Figure 1).
Wherever this has not been possible due to the consolidation of determined urban forms, it has been chosen to realize a transit system that could adapt to such urban forms even through the help of new technologies (“adaptive" public transport). This is the case of cities like Adelaide and Mexico City (Figure 2).

In the case of Munich, Ottawa and Curitiba it was chosen to realize an efficient transit system through “hybrid schemes", that is looking for a balance between the concentration of demand along the corridors of the public transport systems and the development of adaptive systems (Figure 3).

All these examples of transit success are characterized by strong interactions between the land use policy and the transport system planning.

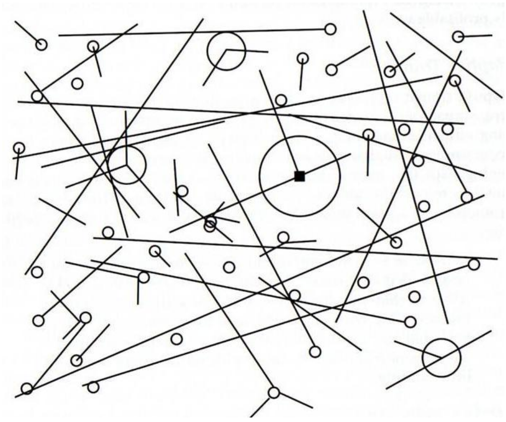

Figure 2 – Adaptive public transport

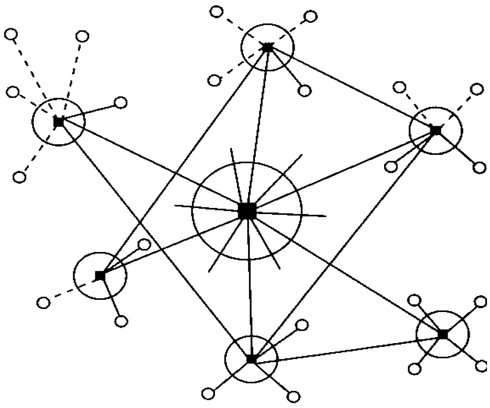

Figure 3 – Hybrid scheme

Similar conclusions are made also by Beimborn *et al.* (1992) about the requirements for successful transit. Land use design could be sensitive to transit needs to develop “transit corridors” separated from the automobile networks of about 0.4-0.8 km, in order to divide the automobile oriented land-use from the transit oriented land-use. Such areas would have a mix of land uses and higher densities to reach a concentration of trip ends along the transit service, with a high quality access system to transit stops.

The importance of a high quality access to transit stops to realize an adequate transit system is underlined also by Schlossberg and Brown (2004) in their works. At the same time, they develop a procedure to analyze if a road network is “pedestrian oriented”: in fact the pedestrian network represents, at a microscopic level, the conjunction element between land-use and transit system. In fact if a urban development is “transit oriented”, it has to be also “pedestrian oriented”.

Extensive debate are also related to the role played by the population and activities densities to explain the level of car and public transport use. Sinha (2003) demonstrates, with the collection of different data from 46 cities in United States, Australia, Canada, East Europe and Asia, that an high urban population density seems to be a primary element to increase transit boardings. These results are reported in Figure 4, where the transit boardings per capital per year increases with the rise of the number of persons per hectare, while the car kilometers of travel per capital per year decrease with the rise of the number of persons per hectare.

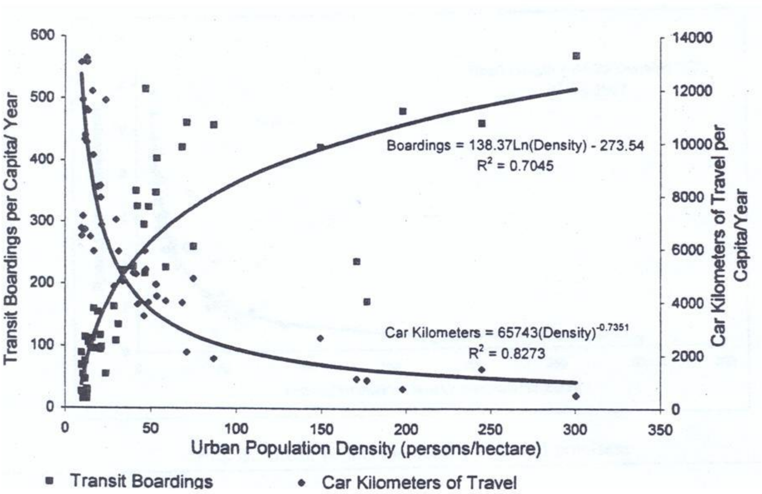

Figure 4 – Impact of density on transit and private transport demand

About the impact of the density, an important observation is highlighted by Eidlin (2005). According to this contribution, the critical issue is not the density values, but its distribution within an urban area. This consideration derives from the analysis of the city of Los Angeles that is characterized by an average density of activities and residences higher than many other Americans cities, but these values are correlated with one of the lower levels of transit share. The comparison with the data of New York and San Francisco, characterized by the largest level of transit use in the US but by an average value of population density lower than Los Angeles, permits to underline that this condition derives from the low differentiation of population and activities density within the territory, that is what the author define as “the worst of all worlds”. As a result, there is a relevant congestion on the roads due to the absolute dominance of the private transport and the consequent compromised situation in terms of air pollution.
From the comparison between urban densities and transport mode shares of Australian, Canadian and United States urban areas, Mees (2009) highlights that variation of densities among cities seems to have little relationship to transport mode share which seems more closely related to different transport policies. The study provides also an extensive analysis about the measure of density. Such data have to be calculated on a consistent and rigorous basis distinguishing between residential and not residential land because different definition could produce different figures.

Facchinetti (2007) describes a series of operations, adopted in the last years in some America’s cities, for the renovation of the surrounding areas of the main transit rail stops. These operations are based on the restructuration and the increase of density in order to realize compact nucleus that can be self-sufficient, with all the necessary activities, with a well-designed pedestrian network and with the presence of different social categories that could live together.

A global literature review about land use and travel relationships is proposed by Ewing and Cervero (2001). The review is conducted to understand if travel variables as trip frequencies, trip lengths and mode choices are correlated with the built environment in the studies analyzed. The land use is classified according to different element: the design of the neighborhood and the activity centers (automobile-oriented, pedestrians-oriented or traditional, etc.); the street networks in terms of street connectivity, directness of routing, block sizes, sidewalk continuity and many other features; land-use patterns measured as residential and employment densities or various measures of land-use mix; urban design features for the character of the space between buildings. The study provides an example of the complexity of the analysis of the connection between land-use and transport system, involving a very large number of social, economic, technical and historical elements not easy to measure and to compare.

A synthesis of the main characteristics that could be identify a sustainable city are made by Banister (2005 and 2006). The total amount of population level (ranging from 50.000 to 100.000 inhabitants) has to be distributed so as to guarantee medium densities (over 40 under 200 persons per hectare), as resulted in empirical studies. Besides, the city should present mixed use developments mainly oriented to public transport accessible corridors and near to highly public transport accessible interchanges.

So, as confirmed in literature, public transport could be seen as a valid alternative to private transport, but to make this possible is necessary to work on its strengths: transit is efficient for concentrated urban areas, wherever there are density values that can develop a certain mobility demand, if it is possible to identify real demand corridors, if it is able to guarantee high “door-to-door" speeds reducing waiting times, transfer times and easy accessibility at stops.

Starting from this background, Gori *et al.* (2006) defines two possible transit oriented development (TOD, Figure 5) to better make use of a mass rapid transit service (high speed and high capacity transit system, usually a rail system):

1. transit-village: with a strong concentration of the activities and the residences in an area of about 500m of radius (considered as the maximal pedestrian distance);
2. compact island: with lower densities, different possible configurations and a maximum extension of about 300-400 hectares (roughly a 2 by 2 km area), in which access to the mass rapid transit system is guaranteed through the introduction of a good quality adduction system able also to assure the area coverage.

In both cases the access phase to the mass rapid transit system becomes fundamental. In fact accessibility can penalize the “door-to-door” speed, increasing the total travel time. For the “transit village”, the access phase has to be identified at the pedestrian level working on the configuration of the road network (in fact the road network is also the network used by pedestrians, Schlossberg, 2004), while for the "compact island" the problem becomes to detect the optimal transit route layout balancing directness and coverage area.

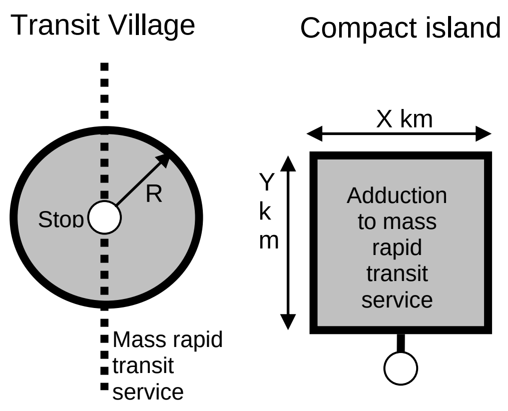

Figure 5 – Transit oriented development (TOD)

The importance of the access phase can be seen in the example reported in Figure 6. The example shows the different values of the total travel times in three cases for the same typical trip in a large urban area. Case 1 describes the total travel times with the usual supply characteristics. If the access speed is doubled (from 4 to 8 km/h) the reduction of total travel time is about 30%, while if the transit speed is doubled (from 42 to 84 km/h) the reduction is only 20%.

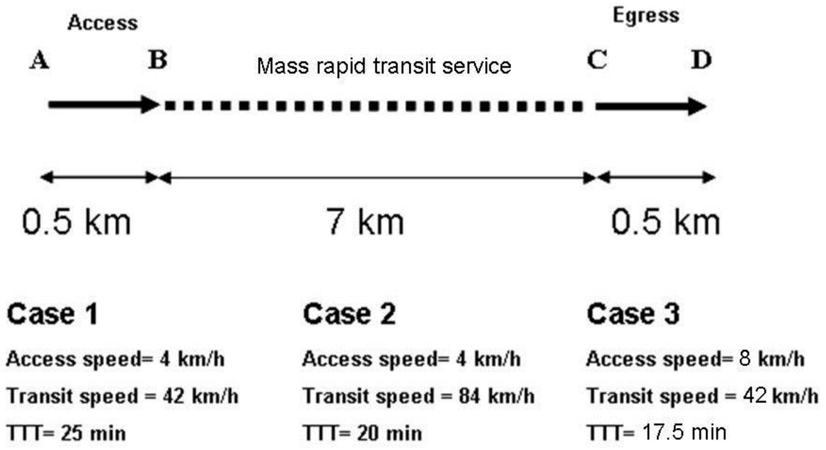

Figure 6 – Importance of access speed in calculation of total travel times

The problems tied to the access phase cover also the microscopic sphere, not treated in the present work, of the pedestrian element and of the evolution of modern urban neighbourhood: in fact the current development of cities does not take into consideration forms of mobility alternative to the automobile and therefore urban neighbourhoods develop according to sparse territorial schemes, marked by clearly separate usage functions. In this context the classic urban structure of the square leaves its place to a longitudinal development of the neighbourhoods and to a following worsening of pedestrian access.

Other elements can be reported in order to construct a competitive public transit system: Cipriani *et al.* highlight the importance of the stop spacing as primary parameter to improve speed and reliability of a bus rapid transit service. In particular they identify an optimal value of stop spacing of about 800 m and, however, always higher than 400-500 m.
Also reserved lanes can play a key role in improving the transit system reliability, moreover it is important to assess the role of information system in order to improve the customer satisfaction.

THE CONSTRUCTION OF A COMPETITIVE PUBLIC TRANSIT SYSTEM: A CASE STUDY

In the previous sections, different elements, criteria and policy have been underlined as important components to build a competitive public transport system and so a more sustainable urban development. In this section, these different approaches (improving the transit system performance or modifying the land use characteristics) are adopted for the case study of the city of Rome with the final aim to analyze the impacts on the demand modal split.

The urban area of Rome is characterized by a population of 2.6 millions and 1.1 millions of employees, for about 552,000 trips in the morning peak hour. A first partition of the urban area can be done considering the area inside or outside the GRA (a circular freeway of approximately 68 km of length). Inside the GRA, the average population density is quite low (about 70 persons/ha) and approximately the same measure is obtained in terms of average employee density (about 75 employees/ha). Outside the GRA, in a very large area (about 90.000ha) the density decreases further to very low values as 6 persons/ha and 1,5 employees/ha even if the population of this external area is larger than half million of persons. In terms of employees, it is also important to underline that about half of the total amount are distributed in the peripheral and in the outside the GRA districts.
About the transit system, there are two metro lines of 36 km length. These lines are radial with a unique interchange in the city centre (Termini rail station). Other five rail lines connect the surrounding areas with the city centre, but these services are actually far from a metro service and only few of them can report an headway of 15 minutes in the peak hour. The join of the rail routes creates an half circle inside the GRA and the assumed closure of this circle is referred as “rail ring”.
Urban bus transport develops for 2,263 km (ATAC, 2009), with 315 frequency service lines, 39 fixed time service lines and 11 express lines. The express lines are thought to connect peripheral districts to the centre with a radial service also in this case. However corridors for express lines are usually shared with the other type of services, so reducing their reliability. The other bus lines are based on an extensive rather than intensive service, with low-medium frequency lines and a very large coverage area.
About the private transport, Rome has a very high level of automobile ownerships (more than 700 for 1,000 persons) and the road network frequently presents congested condition. Large part of the historical centre of the city, one of the main point of concentration of activities, is a

traffic limited zone (ZTL) and the access in the area is permitted only to the residents cars. In many districts of the inside city, there is a relevant lack of space for parking; this trouble is partially overcome by the large use of motorcycles.
The transit share nowadays is estimated to be around 30%.

Infrastructural and land-use evolution scenarios for the Roman urban area

Different scenarios have been simulated to understand the possible evolution of the transit demand share in the Roman urban area. In particular, the simulation of the multimodal network, using the software EMME for the auto and transit assignment (INRO Consultants, 1989), is carried out for the following scenarios:

1. a scenario (scenario 1), for the future horizon of 2020, with supply modifications respect to the current situation according the plans of the local administration;
2. a scenario (scenario 2) in which 12 “transit village” have been created grouping residences, so increasing the population density in these areas to 300 persons/ha;
3. a scenario (scenario 3) in which 5 “transit village” have been created grouping activities, so increasing the employee density in these areas to 250 employees/ha;

A modal choice model calibrated for the Roman context has been used in order to estimate the new transit modal split: it is based on the difference of total travel times using private or transit network and, moreover, it takes into account the reliability (high speed and high frequency) of public transport service. In particular the new public transport demand d_{pub}^{od} can be computed as:

$$d_{pub}^{od} = d^{od} - d_{pr}^{od}$$

where the private automobile demand d_{pr}^{od} derives from:

$$d_{pr}^{od} = \frac{d^{od}}{\left(1 + e^{\beta^t t_{pr}^{od} + \beta^t t_{pub}^{od} + \beta^c c^{od} + \beta^{aff} aff + CSA_{pr} \cdot ASA_{pr}}\right)}$$

and

$d^{od} =$ total origin-destination transport demand

$t_{pr}^{od} =$ travel time between origin *o* and destination *d* using automobile

$t_{pub}^{od} =$ travel time between origin *o* and destination *d* using public transport

$c^{od} =$ monetary cost between origin *o* and destination *d*

$aff =$ reliability of public transport service (dummy variable)

The local administration plan (scenario 1) at 2020 foreseen 2 new additional metro lines respect to the current scenario, plus the extensions of the previous ones. In addition, 11 new rapid feeder services corridors are placed in order to improve the adduction to the future metro network.
The resulting metro network remains a radial network with one point of interchange in the city centre.

From the simulation of the first scenario (Table I), with an increase in the metropolitan network from 36 to 76km and the insertion of 11 new rapid feeder services corridors, the transit demand share increases of only 5% respect to the actual state, although the metro service coverage area reaches more than two million of persons and, in terms of trips attracted, more than the 50% of the total trips inside Rome. Therefore, the construction of additional metro lines, taking into account the very large financial costs and the temporal horizon, seems not to guarantee the desired effects.

Table I – Infrastructural scenario for the Roman urban area

State	Number of metro lines [km]	Transit corridors	Population in the metro basin	Trips attracted by metro basin	Increase of transit modal split
Ref. 2010	2 [36]	-	436.000	148.000	-
Scenario 1 (Project 2020)	4 [76]	11	2.186.600	367.500	+5%

Operating in a complete different way, working on the land use characteristics (Table II), so removing the 11 adduction corridors, concentrating the trips along the coverage area of the metro network and realizing the so called "transit-villages”, does not bring substantial variation in the modal sharing.

The interesting observation (Table II) is that “transit-villages” obtained grouping activities, and so the attracted trips, seem to work better than “transit-villages” obtained grouping residences: in fact with only 5 TODs it is possible to reach the same modal split of the complete infrastructural scenario (scenario 1). Otherwise we need even 12 TODs obtained concentrating generated trips to reach similar modal split.

Table II – Land use scenarios for the Roman urban area

State	Number of metro lines [km]	Transit corridors	TOD [numbers, served trips]	Increase of transit modal split
Ref. 2010	2 [36]	-	-	-
Scenario 2 (2020)	4 [76]	-	[12, generation]	+4%
Scenario 3 (2020)	4 [76]	-	[5, attraction]	+5%

In conclusions however, it is possible to observe that also large improvements in public transport supply or huge modification of the land use characteristics are not sufficient alone to reduce, in a consistent way, the modal split of the private transport. The motivations of these results are investigated in the following paragraphs with a detailed analysis of the mobility and land-use characteristics of the Roman urban area.

MOBILITY AND LAND-USE CHARACTERISTICS IN THE ROMAN URBAN AREA

A detailed analysis about roman urban structure has been done in this section, in order to better understand the previous described results and to verify if the trends and the observations made by numerous authors in literature about the relationships between land use and transportation are confirmed also in the case study of Rome.

It is also important to underline that Rome has to be seen as a very special and interesting urban area in which there is the overlapping of different phenomena: a quite compact centre area respect to the surrounding zones characterized by very low densities, a level of automobile ownerships similar to the American cities rate and a large diffusion of motorcycles as in many cities of developing countries.

A deep analysis has been performed considering the 130 traffic zones which usually represent the districts of Rome. For each traffic zone different indicators have been computed: *(i)* land-use indicators such as population, employees, population per hectare, employees per hectare; *(ii)* mobility indicators such as the transit modal split for generated trips and attracted trips, number of transit stops. Single values are then adopted as basis for computing aggregated indicators that best describe the land-use and mobility behaviour inside the urban area of Rome. For a full review of indicators of each traffic zone, the reader is reported to Table VIII.

A general framework of the Roman urban characteristics is underlined by the range assumed by single indicators of the 130 traffic zones (Table III): on average the land-use reports very low values about density of population and employees (respectively 66 pop/ha and 32 emp/ha), corresponding to low values of transit modal split, especially for attracted trips (18.72%). The number of rail stops takes into account not only the metro lines, but also the five rail lines inside the urban area.

Table III – Land use and mobility indicators range for Rome traffic zones

					Transit modal split [%]		
	Population	Employees	Pop/ha	Emp/ha	Generation	Attraction	Rail stops
Minimum value	163	48	0.04	0.008	2.34	0.10	0
Average value	17,452	7,834	66	32	26.84	18.72	2
Maximum value	77,927	57,306	256	342	54.33	61.62	7

Respect to the partition of the urban area reported before (inside or outside the GRA), Rome can also be divided into 4 circular area (Figure 7): the city centre (zone 1), the area between city centre and the “rail ring” (zone 2), the area between the “rail ring” and the GRA (zone 3), the area outside the GRA (zone 4).

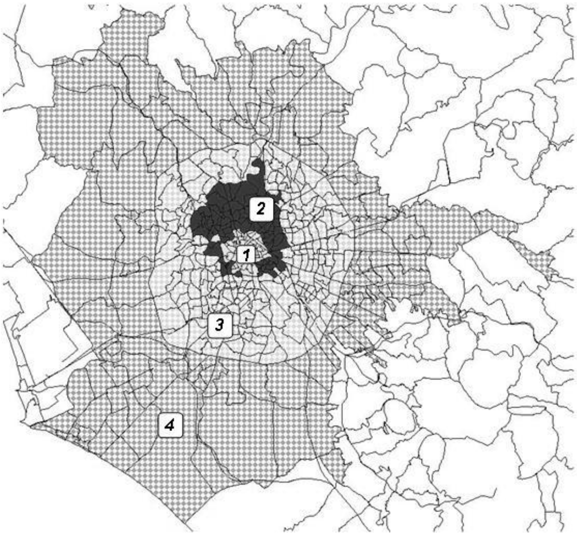

Figure 7 – Partition of the urban area of Rome into 4 macro-zones

Zones 3 and 4 (Table IV) represent the most populated areas (about 85% of the total amount) while especially the city centre (zone 1) covers only the 3.76% of the total population. These data have to be compared with the dimension of each zone: in fact in such a case, zones 1 and 2 demonstrate the higher population density values, while the density decreases strongly moving outside the GRA (6 inhabitants/ha, Table V).

About the activities reported in terms of number of employees, zones 1 and 2 are characterized by the presence of only about 40% of the total amount of employees. Also in this case, the higher activities density values are recorded inside the rail ring, while going outside, employees for hectare decreases to very low values (2 employees/ha, Table V).
Generation and attraction transit modal share (Table V) decrease passing from zone 1 to zone 4 as following the actual metro configuration (two radial lines inside the GRA with a unique interchange in the city centre). This behaviour is particularly stressed for the transit modal share in attraction with values largely less than 20% outside the GRA and higher than 50% in the city centre (Table V).

The generation or attraction rate of trips per hectare (Table V) are quite low for almost all the four areas with the exception of the attraction rate for zone 1 (60.5 trips/ha).

Table IV – Land use and mobility characteristics in the 4 areas of Rome

Zone	Dimension [ha]	Inhabitants	Employees	Inhabitants [%]	Employees [%]
1	1,427	96,472	194,461	3.76%	17.57%
2	3,327	300,344	239,570	11.72%	21.64%
3	29,638	1,588,518	527,690	61.98%	47.67%
4	93,931	577,601	145,299	22.54%	13.13%

Table V – Land use and mobility characteristics in the 4 areas of Rome (2)

Zone	Inhabitants/ha	Employees/ha	Generated trips/ha	Attracted trips/ha	Generation Transit Modal Share	Attraction Transit Modal Share
1	68	136	15.5	60.5	40.78%	52.29%
2	90	72	23.5	37.9	35.44%	42.34%
3	54	18	10.3	8.5	29.34%	19.67%
4	6	2	1.4	0.7	21.99%	8.63%

The previous analyzed data demonstrate the effectiveness of concentrating attracted trips in correspondence of a mass rapid transit service; in fact if there is a high number of activities concentrated in order to reach a high activities density and it happens around a main stop of the metro network (i.e. zone 1), the transit mode seems to be an efficient choice.

However, the situation of Rome is in general far from this type of land-use: in fact passing to a lower level of analysis (from macro-zones to single traffic-zones, Figure 8), the most of the traffic zones are characterized by a very small number of attracted trips (lower than 2,000). Only a small number of such zones (5% respect to the total amount of traffic-zone) has a number of attracted trips greater than 3,000.

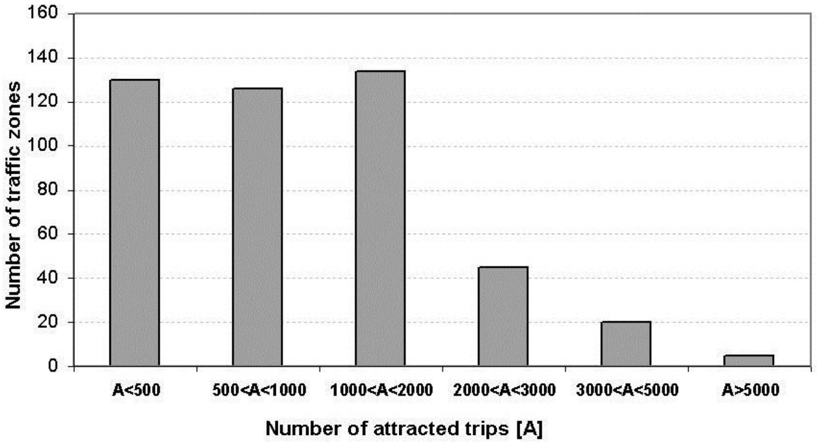

Figure 8 – Classification of traffic zones by number of attracted trips

The observed situation emerges also when calculating the Gini coefficient (G), a statistical index usually adopted to measure the distribution of values observed relatively at a certain variable (in this case the density in an area):

$$G = \frac{1}{n}\left(n + 1 - 2\frac{\sum_{i=1}^{n}(n+1-i)y_i}{\sum_{i=1}^{n} y_i} \right)$$

where:
n = traffic zones
y = density

In the case of Rome, the Gini coefficient has been evaluated both in relation to the localization of the residences and of the activities, obtaining the following values:
GC(residences) = 0.48
GC(activities) = 0.62

Such values show a high dispersion in both cases, mainly for the distribution of the residences: it is clear if we compare these results with the Gini coefficient measured for metropolitan areas such as Los Angeles (CG(residences) = 0.65) or New York (CG(residences) = 0.77), Figure 9. In fact the first one shows a limited Central Business District (CBD) and a typical example of urban sprawl, even if the density value is quite high (4,372 inhab/square mile): this fact brings to a not suitable use of the transit system as reported by the low value of transit modal split (6.7% for work trips, Eidlin, 2005). Otherwise New York, with a lower value of density (3,376 inhab/square mile) respect to Los Angeles, is one of the most “transit metropolis” (26.6% transit modal split for work trips) of United States due to the presence of well-structured CBDs with high density of activities (Eidlin, 2005).

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trips in attraction while for the generated trips, especially for low density, there is an high variation of the transit modal share.

The difference between concentrating generated trips and attracted trips is mainly due to the impact of the access-egress phase to/from the mass transit system: while the access is considered an easily phase, because the trip from the origin zone to the transit stop can be done using different mode (pedestrian, bike & ride, park & ride, kiss & ride etc.), the egress phase from the final stop to the destination is bind by the transit and pedestrian network defined inside the destination zone.

So, if we can develop a main destination point around the stop of a mass transit system so as to promote an easily egress phase, it can encourage the use of transit mode.

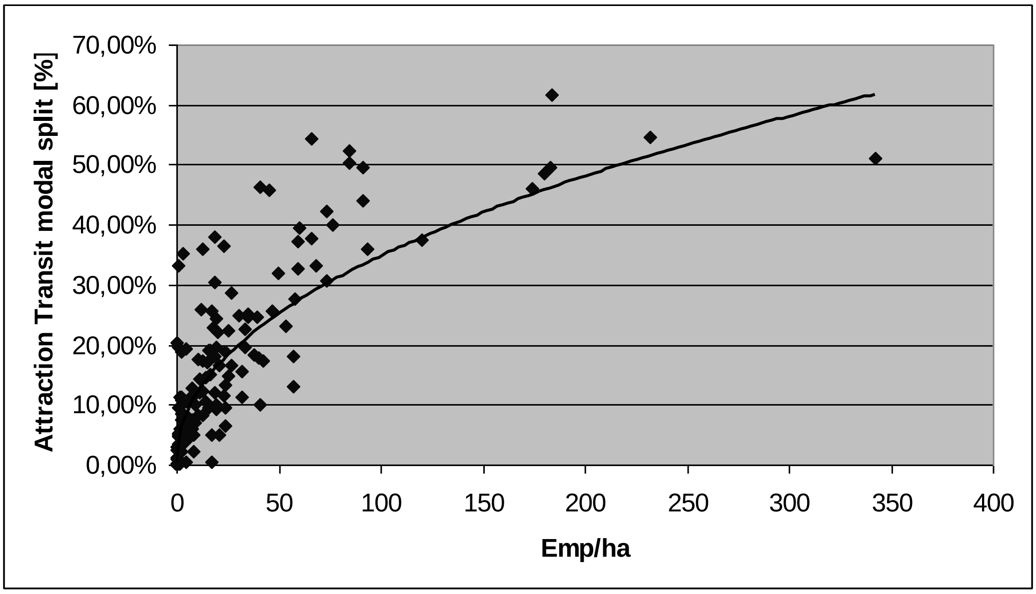

Figure 10 – Relation between activities density and transit modal split for Rome traffic zones

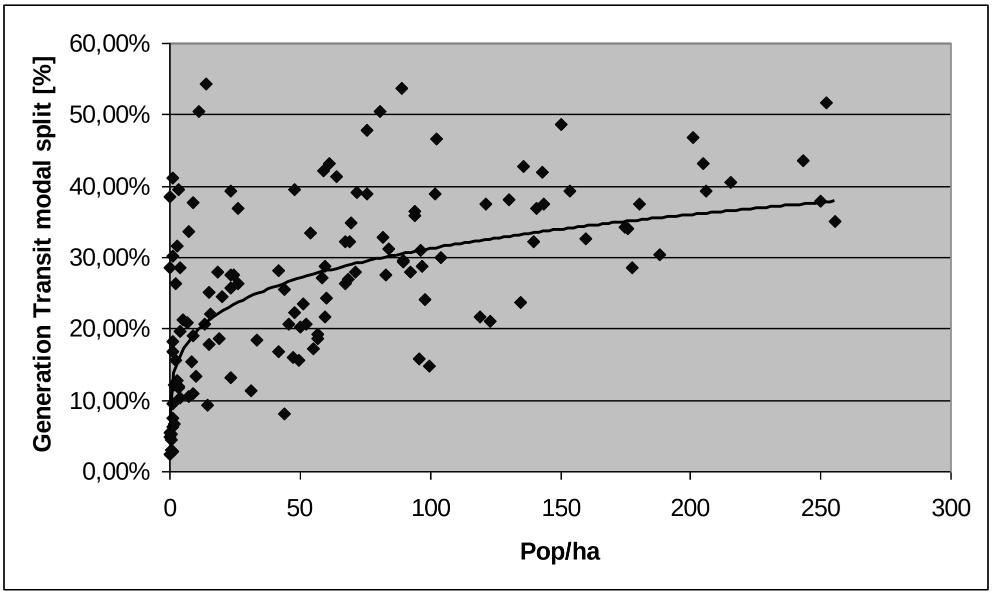

Figure 11 – Relation between population density and transit modal split for Rome traffic zones

These analyses support the results obtained in the roman case: scenario 3 with only 5 “transit village” grouping activities has been demonstrated to be more effective than scenario 2 in which 12 “transit village” have been created grouping residences.

The case study reported in this paper faces with concentration of residences or activities, while no cases have been analyzed in terms of mixed land-use. Define a TOD with mixed land-use is usually referred in literature (Ewing and Cervero 2001, Beimborn *et al.* 1992) as a well-done example of land pattern, however it is quite difficult to define the right level of mixed residences and activities. About this point, some useful considerations can be done from the analysis of population and number of employees of the roman traffic zones and the corresponding values in terms of generated trips rate (generated trips/population) and attracted trips rate (attracted trips/employees).

In Figure 12, the generated trips rate and the attracted trips rate have been compared and four groups of traffic zones have been defined respect to the average values of both the measures (the horizontal and vertical lines):

1. group I where both generated trips rate and attracted trips rate are high;
2. group II where generated trips rate is low and attracted trips rate is high;
3. group III where both generated trips rate and attracted trips rate are low;
4. group IV where generated trips rate is high and attracted trips rate is low.

Group III identifies the traffic zones that most probably don't involve a strong number of generated and attracted trips by automobile or public transport: it means that the zones could be considered self-sufficient zones and, as a consequence, we obtain an indirect measure of mixed land-use. However such values of trips generated and attracted can be also consequence of other parameters (for example low accessibility at the origin/destination points or the presence of elderly people). So, in order to identify the presence of a real mixed land-use able to adequately influence the trips rate, the 55 zones of group III have been analyzed also in terms of population and activities density (Figure 13).

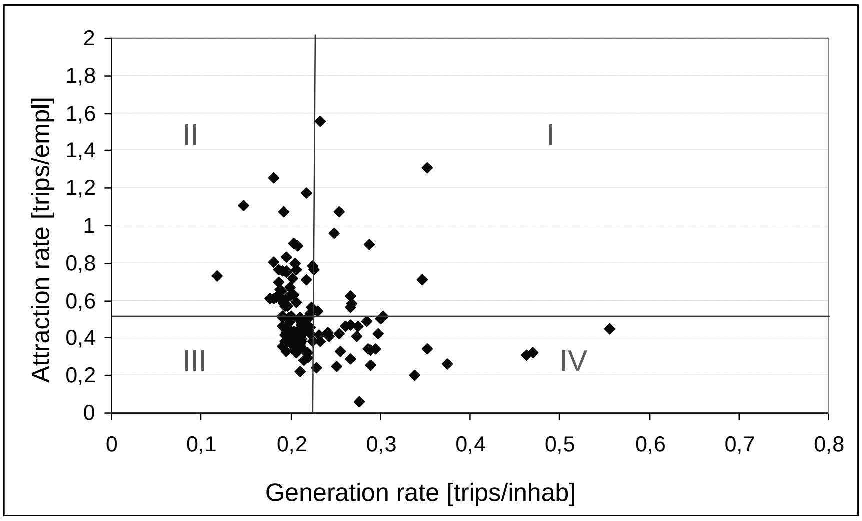

Figure 12 – Relation between generation trips rate and attraction trips rate for Rome traffic zones

In particular, considering a level of population and activities density in order to reach a value of transit modal split greater than 30% (>100 inhabitants/ha and >80 employees/ha from Figure 11 and 10), it is possible to obtain four resulting zones that represent a sufficient level of a mixed land-use for a TOD (Figure 13). The four zones are Nomentana, Salario, Prati and Esquilino (Table VIII) with a population on average equal to 28.000 inhabitants and with a number of employees on average equal to 37.000.

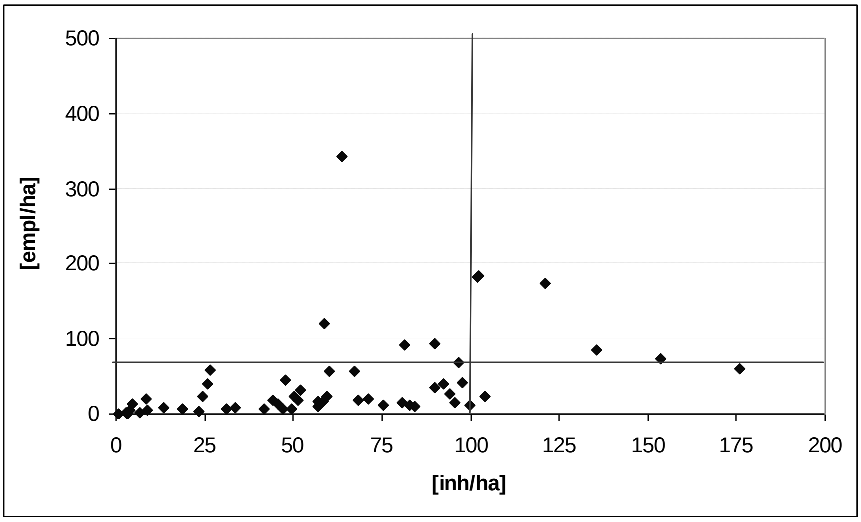

Figure 13 – Relation between population density and activities density for self-sufficient traffic zones

Of course, it is necessary to underline that in order to promote the mass transit system is important to correctly define the dimension of the “transit village”, because also the dimension influences the access/egress phase. In the case study of Rome, the “transit village” has a dimension of about 500 m of radius as reported in literature (Gori *et al.* 2006).

The value of this variable is confirmed by the analysis of Table VI and Table VII. Starting from the current situation, the transit modal share in generation and in attraction of the roman traffic zones are compared with the average distance from the mass rapid transit stops. For distance lower than 500 m, it is possible to observe that transit modal split is larger than 30% for generated trips and about 30% for attracted trips. On the other side, for distance higher than 1 km, the average value of transit modal split and also standard deviation decrease in a very important way.

Table VI – Generation average transit modal split and standard deviation respect to distance to rail stop

Transit modal split	Distance to rail stop [m]			
	< 500	500-1000	1000-1500	>1500
Average	35.45%	21.80%	18.96%	8.69%
St. Dev.	8.80%	11.49%	1.13%	3.89%

Table VII – Attraction average transit modal split and standard deviation respect to distance to rail stop

Transit modal split	Distance to rail stop [m]			
	< 500	500-1000	1000-1500	>1500
Average	29.29%	12.07%	7.86%	3.03%
St. Dev.	14.68%	10.94%	2.51%	2.05%

However, in the roman case “transit villages” demonstrate to not be able alone to modify the usual mobility habits, increasing the transit modal split of only +5%. So, the question is to understand why for the analyzed case study the basic elements and criteria reported in literature are not sufficient to reach a sustainable mobility.

First of all, it is clear that the dispersion of residences and activities, primarily due to the lack of effective land use policy, is one of the most important reasons to explain the results obtained in the different simulations of infrastructural supply and territorial modification in the Roman case. The lack of very high demand corridors and huge attraction poles makes quite useless the extension of the metro network because the new derived transit demand is low respect to the total amount of the population.

Another very important observation is that the existence of a system of huge “transit village” is not a sufficient condition until these TODs are not connected from themselves with an effective transit system. In fact, from a transportation point of view, in the Roman case, there is a lack of the so called “network-effect” due to the configuration of the metro network. The analysis of the demand data deduces the presence of numerous trips not directed in the central area and such trips require, in many cases, different solutions respect to the metro network (not served movements, Figure 14). The lack of other high demand corridors implies that transit service is not competitive and the best, sometimes, only way to satisfy this demand is the private transport.

In the case of public transport, the existing network and also the future one do not have the ability to offer to users similar advantages in terms of travel times, both due to the time losses for the transfers, and above all due to the mandatory crossing from the city centre for the interchange between lines, that is the configuration of the network itself (Figure 14).

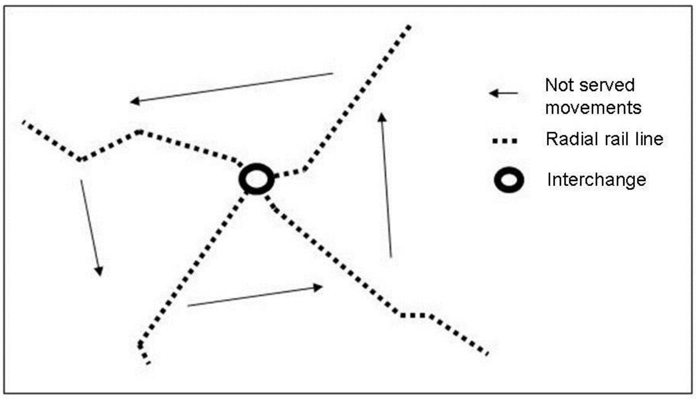

Figure 14 – Radial network and trips without acceptable transit service

If on one side, the macroscopic configuration of the system is not able to guarantee adequate travel speeds, also the access/egress phase could penalize the total "door-to-door” travel speed, fundamental element, as reported before, for the building of an effective public transport system.

The modifications on the land use characteristics through the creation of “transit-villages” are hypothesized also to improve the access phase, but until TODs are not integrated with the transport system network, a sustainable mobility cannot be reached.

CONCLUSIONS

The paper analyzes elements, criteria and policies in order to reach a sustainable mobility based on an efficient transit system competitive with respect to the private transport. The impact of the considered good-practice related to land-use and transport system is tested in terms of demand modal split for the case study of the city of Rome.
The test results lead us to highlight some considerations about the importance of the interaction between land use policy and transportation planning.

A fundamental role is certainly assumed by the density. The density has to be high in order to concentrate trips around a mass-transit stop, so increasing both the accessibility at the starting and ending phase of the trip and, as a consequence, the total "door-to-door" travel speed. Especially the accessibility at destination (egress phase) seems to promote the use of transit system and it depends by the mandatory transit and pedestrian alternatives defined inside the destination zone.

About the mixed land-use, according to the Roman case, a relevant level of population and activities (about 28.000 inhabitants and 37.000 employees) have to be reached to obtain self-sufficient zones with characteristics in terms of density similar to TODs.

However the development of well-designed urban patterns, oriented to receive transit systems (“transit village", more often referred to as Transit Oriented Development - TOD) is not sufficient, by itself, to reach the desired goals (compare Roman case).
It depends by the distribution of density on the territory and, at the same time, by the configuration of the transit network. In fact it becomes essential not only define correctly the TODs, but also to identify the best way to connect such territorial schemes: the optimal connection is essential in order to create a network effect among the public transport systems so maximizing the coverage area, reducing the on-board times and the transfer times.

To build a public transport network is a macroscopic improvements, but it is strictly correlated to the microscopic level (i.e. accessibility, pedestrian and street network at micro level) and to the mesoscopic level (optimal connection of TODs). Given these issues, the building of an effective network has to be investigated, without doubt, in a renewed interaction between the development of the land use and the development of the transport systems.

Future research could be oriented to define this renewed interaction; in particular we hope for a process able to identify the “land use" levels (value and distribution of density of residences and activities) consistent with the capacity at disposal of each element of the transport system. In fact the development of new urban districts usually happens with shorter times respect to the development of mass transit network, so it becomes fundamental to determine location and entity of new residences and activities considering the characteristic of the actual transit system. In such a case we could follow a methodology opposite to the usual planning process, adapting the development of the land-use to the characteristics of the transport systems.

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Table VIII – Analysis of traffic zones in the Roman urban area

					Transit modal split [%]		
Traffic zone	Population	Employees	Pop/ha	Emp/ha	Generation	Attraction	Rail stops
centro storico	22,854	57,306	72	180	39.06%	48.56%	1
Trastevere	12,540	11,884	69	66	32.27%	37.75%	
Aventino	7,401	7,050	48	45	39.49%	45.93%	2
Testaccio	8,446	2,405	143	41	41.92%	46.31%	
Esquilino	31,756	57,021	102	184	46.54%	61.62%	7
XX Settembre	9,006	48,288	64	342	41.40%	51.12%	2
Celio	3,948	8,035	59	120	42.10%	37.42%	
Area Archeologica	521	2,472	3	13	31.54%	35.91%	1
Villaggio Olimpico	2,794	2,609	24	23	27.59%	36.61%	
Parioli	19,888	14,089	97	68	30.93%	33.21%	1
Flaminio	12,484	12,995	90	93	29.35%	35.90%	
Salario	23,276	33,491	121	174	37.53%	46.00%	
Trieste	50,886	17,274	176	60	34.11%	39.62%	
Villa Ada	1,044	1,257	4	4	28.62%	19.39%	3
Villa Borghese	475	2,550	3	18	39.59%	37.97%	1
Nomentana	39,721	24,830	136	85	42.72%	50.33%	2
S. lorenzo	9,191	3,347	180	66	37.57%	54.35%	1
Università	905	23,681	9	232	37.77%	54.75%	1
Montesacro	16,143	3,997	97	24	28.73%	19.00%	
Val Melaina	38,009	4,574	119	14	21.64%	14.53%	
Montesacro alto	33,190	7,784	135	32	23.63%	15.65%	
Fidene	11,278	1,402	100	12	14.89%	8.43%	
Serpentara	27,023	6,069	48	11	22.35%	12.05%	2
Casal Boccone	9,229	2,737	15	5	17.77%	8.16%	
Conca d'Oro	19,808	4,098	160	33	32.69%	19.56%	
Sacco Pastore	9,902	1,381	215	30	40.52%	25.00%	1
Tufello	15,423	2,174	177	25	28.56%	22.53%	
Aeroporto Urbe	2,122	6,176	5	14	21.36%	10.65%	2
Settebagni	4,238	2,314	9	5	19.08%	6.17%	1
Bufalotta	4,298	849	3	1	11.90%	4.82%	
Tor San Giovanni	620	629	0	0	5.42%	1.10%	
Casal Bertone	17,187	7,386	92	40	28.06%	17.81%	
Casal Bruciato	23,693	4,639	94	18	36.50%	18.08%	1
Tiburtino Nord	21,540	4,158	61	12	43.18%	26.02%	4
Tiburtino Sud	26,331	7,407	94	26	35.97%	16.66%	
San Basilio	27,274	11,725	44	19	25.57%	9.37%	
Tor Cervara	2,518	1,540	7	4	10.48%	5.54%	
Pietralata	15,486	5,899	70	27	34.88%	28.62%	3
Csal dè pazzi	28,816	7,917	58	16	27.12%	19.18%	1
Sant'Alessandro	7,467	1,841	7	2	20.85%	5.33%	
Settecamini	8,714	21,553	8	21	15.51%	4.94%	
Tor Pignattara	46,337	10,562	206	47	39.41%	25.72%	6
Casilino	11,725	3,435	60	17	28.73%	22.98%	3
Quadraro	18,895	2,446	130	17	38.15%	25.76%	1
Gordiani	44,435	6,717	250	38	37.98%	18.36%	
Centocelle	53,558	10,238	175	33	34.22%	22.68%	2
Alessandrino	25,898	3,462	83	11	27.58%	14.25%	3
Tor Sapienza	12,452	4,949	59	24	21.59%	9.69%	1
La Rustica	10,248	3,007	57	17	19.23%	5.00%	
Tor Tre Teste	12,443	2,049	96	16	15.90%	9.49%	
Casetta Mistica	679	1,411	2	4	26.44%	5.45%	1
CD Centocelle	1,440	261	7	1	33.63%	11.44%	
Omo	565	6,634	2	23	15.60%	6.65%	
Torre Spaccata	14,745	1,812	84	10	31.25%	17.69%	
Torre Maura	19,452	5,721	71	21	27.94%	16.64%	2
Tor Vergata	17,771	4,218	20	5	24.52%	10.59%	
Acqua Vergine	3,289	2,304	3	2	12.80%	8.56%	2
Lunghezza	29,411	4,562	23	4	13.18%	8.19%	1
Torre Angela	77,927	11,712	47	7	16.00%	12.86%	7
Borghesiana	34,006	5,878	14	2	9.28%	7.60%	6
San Vittorino	6,202	776	2	0	6.62%	2.92%	
Tuscolano Nord	21,879	9,953	201	91	46.80%	49.69%	3
Tuscolano Sud	47,956	15,737	150	49	48.68%	31.88%	4
Tor Fiscale	1,454	665	16	7	22.03%	11.62%	
Appio	28,055	10,410	205	76	43.21%	40.01%	
Latino	22,728	5,480	144	35	37.41%	24.64%	
Don Bosco	56,465	11,951	252	53	51.69%	23.19%	6
Appio Claudio	30,693	6,652	89	19	53.81%	19.53%	

Quarto miglio	9,499	2,980	19	6	18.74%	5.81%	1
Pignatelli	6,753	1,903	68	19	26.94%	10.03%	
Lucrezia Romana	2,461	2,554	14	15	54.33%	17.10%	
Osteria del curato	23,116	5,210	104	23	30.08%	13.38%	1
Romanina	5,392	8,432	26	41	26.32%	10.03%	
Gregna	5,576	3,239	15	9	25.20%	7.04%	
Barcaccia	4,890	1,008	10	2	13.34%	3.47%	
Morena	26,165	6,555	34	8	18.51%	5.04%	1
Ciampino	259	633	1	2	30.29%	2.15%	1
Ostiense	8,013	7,804	76	74	47.81%	42.27%	1
Valco San Paolo	8,440	2,948	54	19	33.51%	30.51%	
Garbatella	45,972	21,862	154	73	39.40%	30.83%	4
Navigatori	5,101	4,331	67	57	32.24%	18.19%	
Tor Marancia	28,022	8,188	67	20	26.33%	22.05%	
Tre Fontane	11,785	11,173	60	57	24.32%	13.19%	1
Grottaperfetta	15,381	9,346	52	32	20.74%	11.28%	
Appia Antica Nord	1,941	2,230	1	1	18.16%	6.09%	1
Appia Antica Sud	394	615	0	1	5.33%	0.10%	
Eur	18,785	41,137	26	58	36.89%	27.76%	4
Torrino	38,215	17,238	50	23	20.23%	11.52%	
Laurentino	25,019	8,875	51	18	23.52%	12.09%	
Cecchignola	15,417	9,977	13	9	20.71%	10.18%	
Mezzocamino	5,767	1,102	11	2	50.49%	18.82%	2
Spinaceto	25,244	4,501	57	10	18.72%	8.19%	
Vallerano	13,919	5,303	4	1	11.68%	2.98%	
Decima	4,815	828	1	0	9.56%	2.49%	1
Porta Medaglia	1,715	217	1	0	3.11%	0.10%	
Castel Romano	235	825	0	1	4.95%	3.22%	1
Santa Palomba	530	2,191	1	4	7.43%	0.41%	
Malafede	7,846	673	18	2	27.92%	11.32%	1
Acilia Nord	21,317	2,186	23	2	25.73%	11.31%	1
Acilia Sud	21,317	2,186	23	2	39.38%	10.84%	
Palocco	23,018	3,724	23	4	27.58%	7.86%	
Ostia Antica	9,211	1,492	4	1	19.76%	9.64%	1
Ostia Nord	42,956	6,998	75	12	38.86%	17.42%	1
Ostia Sud	35,972	6,758	81	15	50.46%	19.19%	3
Castel Fusano	1,129	327	1	0	41.06%	20.39%	2
Infernetto	10,740	1,253	9	1	10.92%	5.08%	
Castel Porziano	259	48	0	0	2.34%	0.36%	
Marconi	33,987	7,879	256	59	35.00%	37.21%	
Portuense	29,537	6,051	123	25	21.15%	14.77%	1
Pian Due Torri	25,725	3,579	140	19	32.27%	24.36%	1
Trullo	28,271	4,824	42	7	16.88%	11.36%	1
Magliana	1,576	19,539	1	17	2.83%	0.58%	1
Corviale	14,546	2,827	31	6	11.39%	7.85%	
Ponte Galeria	6,037	2,915	1	1	12.07%	5.30%	1
Colli Portuensi	36,256	15,699	98	42	24.20%	17.28%	
Buon Pastore	30,743	8,642	46	13	20.59%	12.32%	
Pisana	3,012	3,495	4	4	10.40%	4.02%	
Gianicolense	55,279	17,454	188	59	30.42%	32.73%	2
Massimina	6,093	1,165	44	8	8.14%	2.26%	
Pantano di Grano	2,816	1,569	1	0	4.44%	1.31%	1
Villa Pamphili	163	73	1	1	16.75%	19.63%	
Prati	17,954	32,216	102	183	38.97%	49.60%	2
Della Vittoria	25,775	28,805	82	91	32.83%	43.97%	2
Eroi	20,453	7,097	243	84	43.56%	52.47%	3
Aurelio sud	25,413	9,787	90	35	29.63%	25.08%	1
Val Cannuta	29,620	11,324	42	16	28.20%	15.00%	2
Fogaccia	26,005	3,616	55	8	17.27%	6.08%	
Aurelio Nord	18,717	5,178	141	39	36.89%	24.56%	2
Casalotti di Boccea	15,422	2,264	50	7	15.55%	7.60%	
Boccea	4,574	1,784	1	0	6.22%	3.47%	