

THE MARGINAL ACCESS COST: A NEW INDICATOR FOR SUSTAINABLE URBAN DEVELOPMENT

Agostino Nuzzolo

Department of Enterprise Engineering, "Tor Vergata" University of Rome, Italy

Pierluigi Coppola

Department of Enterprise Engineering, "Tor Vergata" University of Rome, Italy

Enrica Papa

AISSR, University of Amsterdam, The Netherlands

1. INTRODUCTION

Accessibility is a key concept in integrated Land-Use and Transport (LUT) planning; it can be of great support for those decision-making processes aiming at planning sustainable urban development, as well as at evaluating the effects of transport plans under a wider perspective. However, while there is a large body of literature focusing on the theoretical definitions and measurements of accessibility (Handy & Niemeier, 1997; Geurs & van Eck, 2001), the extent to which such measures are useful in assessing the most appropriate interventions is less clear (Geurs & van Wee, 2004; Curl et al. 2011). Straatemeier (2008) suggests that the theory is not well applied in practice.

The gap between the clear theoretical assumptions and the infrequent applications of accessibility tools in planning practice shows the need to maximize the usability of accessibility instruments and measures. In a recent survey on accessibility instruments developed under the COST Action "Accessibility Instruments for Planning Practice" (Hull et al., 2012), some interesting remarks have been highlighted: 1) accessibility measures are in some cases too complex, abstract, hard to comprehend and to interpret for non-modellers, including planners; 2) indicators must remain sufficiently simple and intuitively meaningful to be used in public forums and to be widely accepted but at the same time should be founded on strong methodological basis.

Two additional specific characteristics in our opinion are required for accessibility measures to be efficiently used in LUT planning processes:

1. the need of accessibility measures to embody also externalities' assessment, whereas most of the proposed indicators assume a subjective perspective either that of the individuals or that of the opportunities/activities, without including any environmental impacts evaluation;

2. the need of a clear unit of measure, easy to interpret and to be communicated to public stakeholders, whereas accessibility indicators are in general a-dimensional, usually corresponding to an index varying in a numeric scale that does not have any unit of measure, especially the most sophisticated one.

Starting from the above considerations, the goal of this paper is to propose an indicator i.e. the “Marginal Activity Access Cost” (MAAC) filling the gap between strong theoretical basis and the usability in practice, overcoming some limitations of the existing accessibility measures. The proposed indicator computes the cost for the community of locating new activities in a particular zone of the study area, providing an estimation in monetary terms of the impacts on mobility (i.e. additional generalized travel costs) and on the environment (e.g. the pollutant emissions due to the additional mobility by car).

The remaining of the paper is organized as follows. Section 2 describes the “Marginal Activity Access Cost” (MAAC) indicator. Section 3 proposes a classification comparing the MAAC with the existing accessibility measures. In section 4 applications to the urban area of Rome are discussed. In section 5 some conclusions are drawn.

2. THE MARGINAL ACTIVITY ACCESS COST (MAAC)

The MAAC is an aggregate (zone-based) indicator (expressed in monetary terms) aiming at estimating the costs due to the location of a new single activity in a given zone, on the mobility (i.e. internal costs) and on the environment (i.e. external costs). In fact, locating new activities in a zone can induce on the one hand additional commuting trips, but, on the other hand modify also the potential the zone has to satisfy traveller’s needs (i.e. the zone attractiveness), and thus, can change the mobility flows in the whole study area. Activities are here expressed in terms of people employed; “one single new activity in the specific zone o ”, thus, means an increment of “ n ” employees in zone d , “ n ” being the number of employees of the activity itself.

The MAAC is computed as the difference of access cost to the zone d , with and without the new activity, under the assumption that the Origin-to-Destination (OD) generalized travel costs is constant; in other terms, the additional mobility induced by the activity has no impacts on network links congestion and on the spatial distribution of other activities in the study area. To keep this assumption valid, the number of employee of the new activity should be small enough, e.g. be equal to one.

The MAAC of a zone “d” includes two components: the internal costs, i.e. the generalized travel cost (times and cost on auto and public transport) both of people employed in the new activity (i.e. commuting costs) and of people “attracted” by that activity for other purposes (e.g. shopping); and the external costs, e.g. the pollutant emissions related to the additional trips those people make by car. Therefore, MAAC can be computed as:

$$MAAC(d) = IMC(d) + ETC(d)$$

where the first component, “Induced Mobility Costs” (IMC), measures the incremental mobility costs due to trips generated by the activity (i.e. for commuting and other purposes), and the second component, “External Transport Costs” (ETC), measures the impacts that such induced trips generate on the environment, e.g. in terms of air pollution and noise.

2.1 Induced Mobility Costs (IMC)

The induced mobility costs (IMC) component is measured as the incremental generalized travel cost induced by the location of one single new employee in a given zone d, keeping constant the distribution of other activities and the transport network performances (link travel times). It consists of two terms:

1. commuting mobility cost, related to the home-to-work trips of the new employee in the activities of zone d;
2. other purposes mobility costs, related to the flows of users attracted by the zone for other purposes (e.g. for shopping and leisure).

Thus, the IMC component can be expressed as:

$$IMC(d) = \sum_O \Delta d_{Od} \cdot C_{Od} \quad (1)$$

where:

- Δd_{Od} is the sum of the commuting trips and of those trips made for other purposes, induced by the location of the new employee in zone d;
- C_{Od} is the average travel cost from O to d using the available transport modes (e.g. auto and public transport).

The induced demand, Δd_{Od} can be computed as follows:

$$\Delta d_{Od} = p_{loc}(O|d) + \sum_s [E_s(O) \cdot \Delta p_{other}(d|O)] \quad (2)$$

where:

- $p_{loc}(O|d)$ is the probability of residing in zone O of the new employee in zone d; this can be estimated using residential location models conditional to workplace (see, for instance, Coppola & Nuzzolo, 2011);
- $E_s(O)$ is the number of trips generated from zone O for purpose s, s being several purposes but commuting; this component can be estimated by trip frequency models;
- $\Delta p_{other}(d|O)$ is the variation in the probability of choosing zone d as destination for several purpose but “workplace”, conditional to living in zone O; this can be estimated by trip distribution models.

To compute the MAAC, spatial Land-Use Transport Interaction (LUTI) models, particularly residential location models, trip generation-attraction and modal split models, are needed. In the application presented in the next paragraph, the LUTI model STIT (Nuzzolo & Coppola, 2005) is adopted. This allows to estimating the spatial distribution of the residents' conditional to workplace and the origin-destination matrices by mode and purpose, using random utility models.

The OD travel cost, C_{Od} , is expressed in monetary term, and can be estimated as follow:

$$C_{Od} = \%auto_{Od} \cdot (tt_{Auto,Od} \cdot VOT_{Auto} + mc_{Auto,Od}) + \%PT_{Od} \cdot (tt_{PT,Od} \cdot VOT_{PT} + mc_{PT,Od}) \quad (3)$$

where:

- $\%auto_{Od}$, $\%PT_{Od}$ are the modal shares of auto and public transport modes on the OD pair Od;
- VOT_{Auto} , VOT_{PT} are the values of times for travellers using auto and public transport modes respectively (in Euro/hour);
- $tt_{Auto,Od}$ is the travel times (in hour) by auto on the origin-destination pair Od;
- $tt_{PT,Od}$ is the travel times (in hour) by public transport on the origin-destination pair Od, including on-board time, waiting time and access-egress time;
- $mc_{Auto,Od}$ $mc_{PT,Od}$ are the monetary costs using auto and public transport modes respectively, on the origin-destination pair Od.

2.2 External Transport Costs (ETC)

External Transport Costs (ETC) component, usually referred to as “externalities”, measures the impacts on the environment and on the public health, such as: air pollution, noise, climate change, visual intrusion, resource consumption, and so on. European-wide reviews of external costs of transportation are provided in several studies including IMPACT (Mailbach *et al.*, 2008) and HEATCO (Odgaard *et al.*, 2005).

In this study, the external transport costs component is measured as the incremental external cost due to additional distances travelled by car, induced by the location of one new employee in a given zone d . It includes climate change, air pollution, noise, road safety and congestion. The External Transport Costs (ETC) component can be expressed as:

$$ETC(d) = \sum_o \sum_i \Delta veich_{od} \cdot dist_{od} \cdot \alpha^i \quad (4)$$

where:

- $\Delta veich_{od}$ is the sum of the induced trips by car (converted into vehicles), including commuting trips and those for other purposes, induced by the location of the new employee in zone d ;
- $dist_{od}$ is the distance on the road network between zone O and zone d ;
- α^i is the unitary external cost (expressed in Euro/Vehicle-Km); this value has been adapted to the case study based on the literature, see for example the values reported in Table 1.

Table 1 Unitary external cost expressed in Euro/Vehicle-Km (Uniontrasporti, 2009)

	Climate change	Air pollution	Noise	Accidents	Congestion
Passenger trips [cent €/vehicle-km]	4.50	18.62	10.08	20.92	16.85

2.3 Remarks

The MAAC is an indicator conceptually different from accessibility but that can be used for the same purpose of supporting the spatial planning process in light of sustainability goals. It depends on the typology of activity to be located, e.g. commerce, education, services which may attract a differentiated number of trips. Therefore, several types of MAAC indicators can be defined according to activity sectors. Moreover, since such impacts vary from zone to zone, the proposed indicator gives an estimation of the differentiated impacts of locating activities in different zones of the urban area, and could be useful to assess land-use and transport development policies in compliance with the goal of reducing the overall transport cost.

With respect to other (passive) zone-based accessibility measures proposed in the literature, the MAAC does not measure the “opportunities” of an activity to be reached but the total cost (internal + external) the community has to pay if a new activity is located in an urban zone. Indeed, it considers not only the “users costs” to reach the new activity (such as some aggregated accessibility measures do) but also the external transport costs related to the atmospheric and noise pollution.

In converting such cost components in monetary terms (i.e. Euro), the MAAC has a clear and easy communicable unit of measure which constitutes a great advantage for the stakeholders engagement and in sharing results, as it can be easily understood.

3. ACCESSIBILITY VS. MARGINAL ACTIVITY ACCESS COST

The concept of accessibility has been widely used by transportation and land use geographers, engineers and planners for several purposes: a) to understand and model land-use and transport interactions; b) to assess transports plans with respect to equity and sustainable planning goals; c) to solve optimal activity location problems.

Accessibility measures represent the relationship between the land use system and the transportation system serving it. They express the ease of the activities/opportunities located in a zone to be reached by potential users (clients, workers, carriers, service providers, etc.), i.e. “passive” accessibility (Hansen, 1959; Ben-Akiva and Lerman, 1979), or how individuals located (e.g. residing) in a zone, could reach activities located in other zones of the urban areas, i.e. the “active” accessibility (Cascetta, 2009).

In literature several taxonomies have been proposed, according to different criteria (Geurs & van Eck, 2001; Geurs & van Wee, 2004; Curl et al., 2011). Here we propose a classification (Table 2) based on whether the measures do include or not any behavioural component. Accordingly, we distinguish two classes of accessibility measures:

- Behavioral (or individual) based, defining accessibility from a single user/activity subjective perspective;
- Not-Behavioral (or zone) based accessibility measures, that define accessibility based on potential opportunities spatially distributed in the zones of the study area.

Such classification is consistent, and partly derive from the assumption that accessibility can be defined either from the individuals viewpoint (behavioural measures), or from a geographical impersonal perspective, related to the zones of the urban area (not-behavioural measures).

To the first cluster, belong the “utility-based” accessibility measures, derived from Random-Utility Maximization (RUM) theory (Ben-Akiva & Lerman, 1985), and the “contour measures”, also referred to as “opportunity-based” measures.

Utility-based measures are founded on the paradigm that individuals aim at maximizing the net utility of participating in activities located in an area. They can be further classified into “trip-based” and “activity-based”. Trip-based measures consider one trip at a time, not taking into account the daily schedule of the activities or any trip chaining. They assume each trip is independent from the others made not only in the same day, but also in the same journeys. On the other hand, activity-based measures (Dong et al., 2006) also defined in literature as “time-space” measures (Kwan, 1998), do estimate accessibility in terms of individual ease of access to activities, taking into account the daily activity schedule and the related trip chain as well as the spatial and temporal constraints of each activity. They contributed to extent

the definition of accessibility by incorporating innovative concepts such as trip chaining, daily schedule and duration of the activities undertaken.

Utility-based measures are formally very robust and are based on strong theoretical paradigms. They can represent accessibility at individual level according to discrete preferences, but have some drawbacks: complexity and data requirement are the main barriers to their implementation. Moreover, the results are not expressed into physical units of measure, so that they cannot be easily interpreted and are difficult to be transferred across different territorial contexts.

Contour measures define accessibility as the number of opportunities that can be accessed within a given distance or travel time or generalized travel cost, from a specific location in the study area (e.g. a station, a building, etc.). These measures require the definition of the threshold of the maximum travel times (or generalized cost) acceptable for individuals to reach the opportunities (Ingram, 1971). They are here classified as behavioural, because they include a subjective component (although this is not fully and immediately recognized) in that the threshold values vary with individuals' preferences, taste and habits.

While easy to understand and to compare, contour measures have a high sensitivity towards such threshold values, which need to be calibrated upon disaggregate individual data and are difficult to be computed in practical application. In fact, not all the opportunities are perceived in the same way by individuals. To overcome such drawback, Cascetta et al. (2013) have introduced the concept of perceived opportunities in the definition of this type of accessibility measures.

To the second cluster of accessibility measures, belong the “network-based” and the “gravity-based” measures. These classes of indicators define accessibility in relation to the potential opportunities available in the zones spatially distributed in a given study area.

Network-based measures, founded on graph theory, are based on the characterization of the topological (relational) properties of spatial networks; according to them, accessibility is directly related to the concept of the network centrality of a node. Five different measures of centrality can be defined: degree, closeness, betweenness, straightness and information (Crucitti et al., 2006). Degree centrality defines accessibility of a node proportional to the number of links connecting that node to all the others. Closeness centrality compute to what extent a node i is close to all the other

nodes along the shortest paths in the network. Betweenness centrality is based on the definition that a node is central as much as it is crossed by shortest paths connecting origin-destination pairs. Straightness centrality, originates from the assumption that the efficiency in the communication between two nodes i and j is equal to the inverse of the shortest path length d_{ij} . Information centrality relates node significance to the ability of the network to respond to the deactivation of the node itself. Network measures, can have important shortcomings for accessibility, social and economic evaluations, but they ignore potential land-use impacts of transport strategies.

Gravity-Based measures, so-called according to Isaac Newton's Universal Law of Gravitation, define accessibility proportional to the number of activities/users that can be reached, and inversely proportional to travel distance or travel times or generalized travel costs (Hansen, 1959). Gravity-based measures depends on two factors: an attractive factor (i.e. the mass) measuring the total number of potential users located in the zones of the study area d , and an "impedance function" representing the generalized travel cost between the zone o (for which accessibility is computed) and all the other zones d . One of the major difficulties of this accessibility measure is the need to estimate the parameters to weight masses and impedance factors.

In Table 2 we propose a comparison between the classified accessibility measures and the "Marginal Activities Access Cost" (MAAC), according to the principles of theoretical basis, communicability, operationalization and usability for sustainability assessment.

Compared to the other accessibility measures, the MAAC indicator has stronger theoretical basis than contour and network-based measures; at the same time the MAAC has better communicability features than utility based and gravity based measures, and can be used for sustainability assessment process as it takes into account also the external costs. One weak point of the MAAC is the operationalization, as it necessities, as the gravity based and the utility based measures, a considerable amount of data and model estimation to be computed.

Table 2: Accessibility measures comparison

Cluster	Accessibility measures	Theoretical basis ^a	Communicability ^b	Operationalisation ^c	Usability for sustainability assessment ^d
Behavioral (individual - based)	Utility-Based/Random utility measures	±	-	-	-
	Activity-based random utility measures (time-space)	±	-	-	-
	Contour /cumulative opportunity	-	+	±	±
Not behavioral (zone – based)	Network-based	-	+	+	-
	Gravity-based	±	-	-	±
	MAAC	+	+	-	+

a Score: + strong theoretical bases ; ± moderately strong; - weak theoretical basis;

b Score: +easy to communicate or interpret; ±moderately difficult; - difficult;

c Score: +easy to operationalize; ±moderately difficult; - difficult;

d Score: +easy to use; ±moderately difficult; - difficult;

4. APPLICATION TO THE CASE STUDY OF ROME

The proposed MAAC indicator has been validated through an application to the city of Rome, which is the Italian most populated urban area, with 2.8 million residents in 1,285.3 sqkm and 1.1 million employees, contributing to about 600,000 trips in the morning peak hour. The urban structure of Rome is strongly mono-centric. It can be split into circular rings with increasing densities approaching the city center. The “Grande Raccordo Anulare” GRA, i.e. the circular freeway of approximately 68 km of length, delimits the most dense and populated area, with an average density of population of about 70 inhabitants/ha and an average density of employees of about 75 employees/ha. Inside the GRA population and activities are mainly placed along radial roads to/from the city center (i.e. the access roads to the ancient roman town). The transit system consists of two (as well radial) metro lines with a total length of about 36 km, with only an interchange node in the “Stazione Termini” central rail station. Seven regional rail lines connect the

surrounding urban areas to the city center. Rome has a very high level of automobile ownerships (more than 700 for 1,000 persons) and the road network is highly congested. In large part of the historical center, access by car is allowed only to the residents and public transport vehicles.

The application has been implemented into three steps, related to three separate objectives: 1) to explore the potentiality of the MAAC indicator, 2) to compare it to the gravity-based passive accessibility index and 3) to use it to assess the new urban development choices made by the new Master Plan of the municipality of Rome, i.e. “Piano Regolatore Generale”.

4.1 MAAC validation

MAAC has been calculated referring to a zoning of the study area consisting of 463 zones. To the scope of our analysis, a set of zones has been selected according to proximity to city center (CBD) and to zone connectivity to Public Transport (PT), measured as the connectivity of the zone by metro.

It can be observed that the MAAC is inversely correlated to the proximity to CBD (Figure 1): the more a zone is far from the city center, the bigger is the MAAC. This depends on the fact that for central zones (i.e. zone located in a barycentric position with respect to residents and to other activities) the average trips length, and consequentially the (internal and external) access cost is lower than for the peripheral ones.

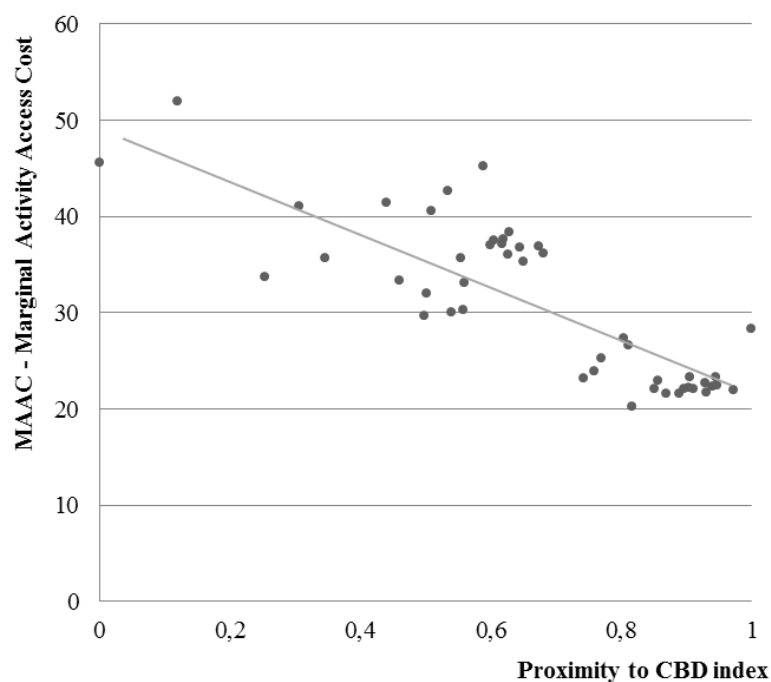


Figure 1. Scatterplot between MAAC and the Proximity to CBD

With respect to the zone connectivity to Public Transport a similar pattern can be identified only for peripheral zones (Figure 2), whereas MAAC for central zones, i.e. the zones with higher connectivity to Public Transport, is almost invariant w.r.t. connectivity to PT. This depends on the fact that the increase of mobility due to new activity in central areas is marginal with respect to the demand volumes already attracted by such zones in the reference scenario (i.e. without the new activity). Moreover central zones have lower External Transport Costs (ETC) due to less volume of vehicles directed towards these zones: fewer trips by car means lower emissions and therefore smaller external costs.

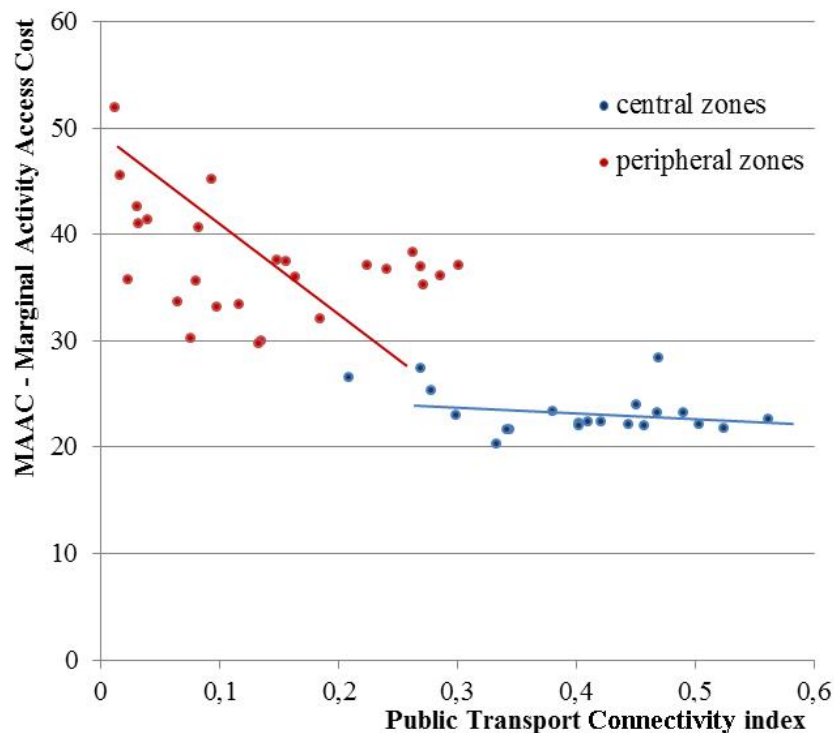


Figure 2. Scatterplot between MAAC and Public Transport Connectivity index

This is confirmed also by the fact that zones with higher connectivity by public transport present a lower External Transport Costs (ETC) relatively to the Induced Mobility Costs (IMC) components (Figure 3), due to preminent connectivity to public transport towards such zones.

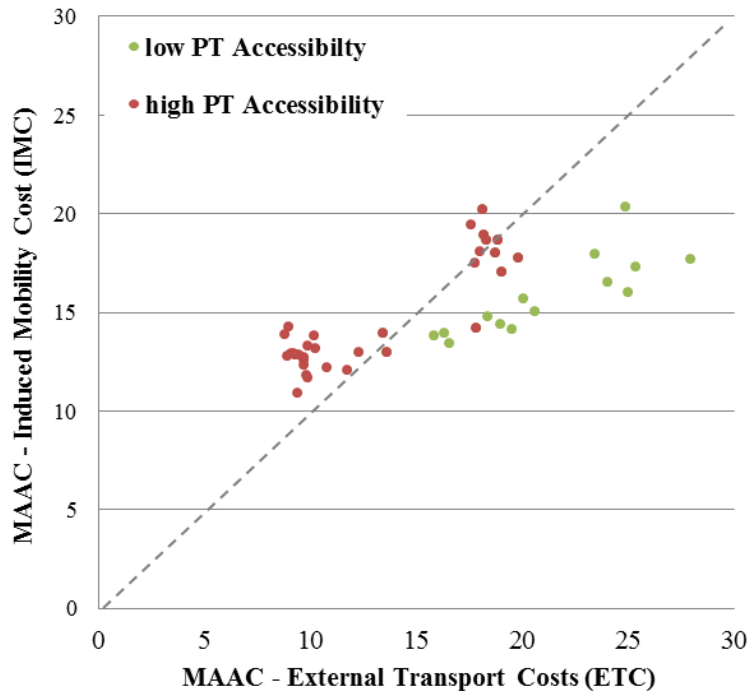


Figure 3. External Transport Cost (ETC) vs. Induced Mobility Cost (IMC)

The scatterplot in Figure 4 shows a comparison between the component of Induced Mobility Cost (IMC) related to the commuting trips and the component of Induced Mobility Cost (IMC) related to the trips for other purposes. Three main clusters of zones can be identified for central areas, semi-peripheral areas and peripheral areas of the study area.

For central areas, the component for other purpose is slightly higher than the one for commuting, but this difference is not very substantial due to the fact that the average travel distance towards central zones is similar for commuting and for other purposes.

On the other hand, in semi-peripheral zones the “other purposes” component is preeminent to the commuting component. The explanation arises from the consideration that the distance of the residence zone from the workplace zone is within a range that does not vary with the distance from the city center; in other terms wherever the workplace is located, either in the city center or in the suburb area, the average distance home-to-work (and thus the average commuting access cost) is almost invariant. This is not true for other purposes trips where the average access distance is greater for peripheral zones than for the more central zones.

For peripheral area the commuting cost is higher than the cost of trips for other purposes, since in such area the mobility volumes induced by other purposes is very low due to the absence of agglomerations (i.e. low number of activities) and the distance to residential zones; therefore, the induced mobility cost are mainly related to commuting.

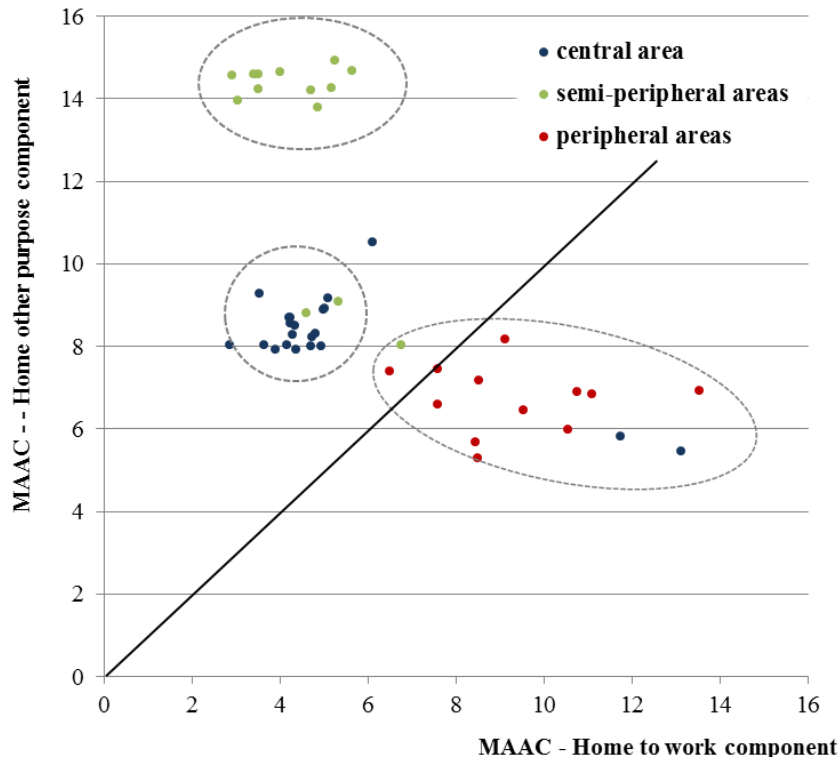


Figure 4. MAAC component: commuting trips vs. to trips for other purposes

4.2 A comparison between MAAC and gravity-based passive accessibility index in Rome

A second step of the application consists into the comparison of the MAAC values with an accessibility index. The latter has been computed as the gravity-based passive accessibility of the firms to the households (Coppola & Nuzzolo, 2011):

$$Passive_Acc(d) = \sum_o HH(o)^{\alpha_3} \cdot \exp(\alpha_4 \cdot C(o,d)) \quad (5)$$

where:

- HH(o) is the number of households (expressed in thousands) in the zone “o”;
- C(o,d) is the generalised travel cost between zones “o” and “d”;
- α_3 α_4 are two estimated parameters.

In order to compare the values of these two different indicators, they have been normalized in a (0,1) scale. Table 3 denotes the average values of the indexes for five zone clusters identified according to proximity to city centre and to connectivity by Public Transport (Figure 5).

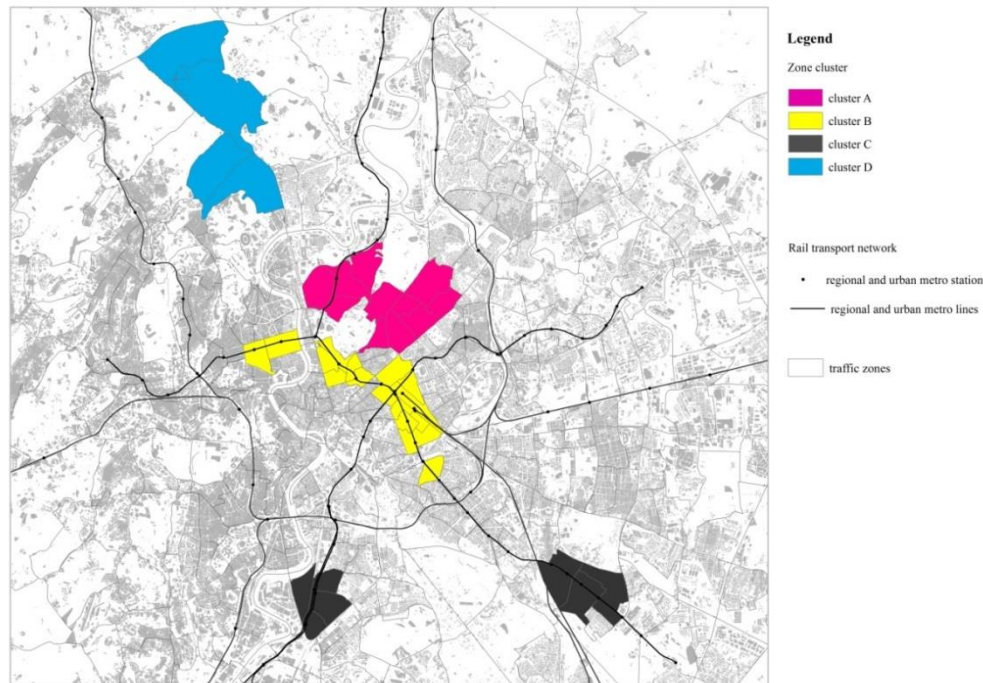


Figure 5. Selected zones clusters (A, B, C, D)

The MAAC is by definition dual to accessibility, i.e. zones with higher accessibility should correspond to zones with lower MAAC. This is confirmed by the average index values reported in Table 3 where it can be observed that zones with higher proximity to CBD and high connectivity by PT (cluster B) are those with lower MAAC and higher accessibility, as well as peripheral zones with very low connectivity by PT (cluster D) are those with lower accessibility and higher MAAC.

Table 3. MAAC index (IMC plus ETC) vs. Passive (Gravity-based) Accessibility index for zones clusters

Zones cluster	Gravity-based passive accessibility index	MAAC index
A	0,75	0,10
B	0,78	0,09
C	0,65	0,52
D	0,57	0,48

Moreover, it can be observed that MAAC is more affected by the proximity to CBD than to accessibility. Indeed, the MAAC index for central zones (cluster A and B) is five times lower than for peripheral ones (clusters C and D), whereas the accessibility indexes for central zones is 1.3-1.5 times those for peripheral zones. This is due to the fact that MAAC includes also external transport costs which are higher for peripheral zones where the mobility by car is preeminent than for central zone, and such component is typically not included in accessibility measures. As consequence, also the differences in MAAC between different clusters present a higher degree of variance, while accessibility differences among clusters are more uniform.

4.3 MAAC for assessing new activity location in the Rome metropolitan area

In a final step of the application the MAAC was used to assess the new activities location choices proposed by the new Urban Master Plan. In particular, we computed the marginal activity access cost to the “new centralities” defined by the plan, i.e. new urban developments along the rail network axis, in which develop new settlements with about 120,000 new employees (Figure 5).

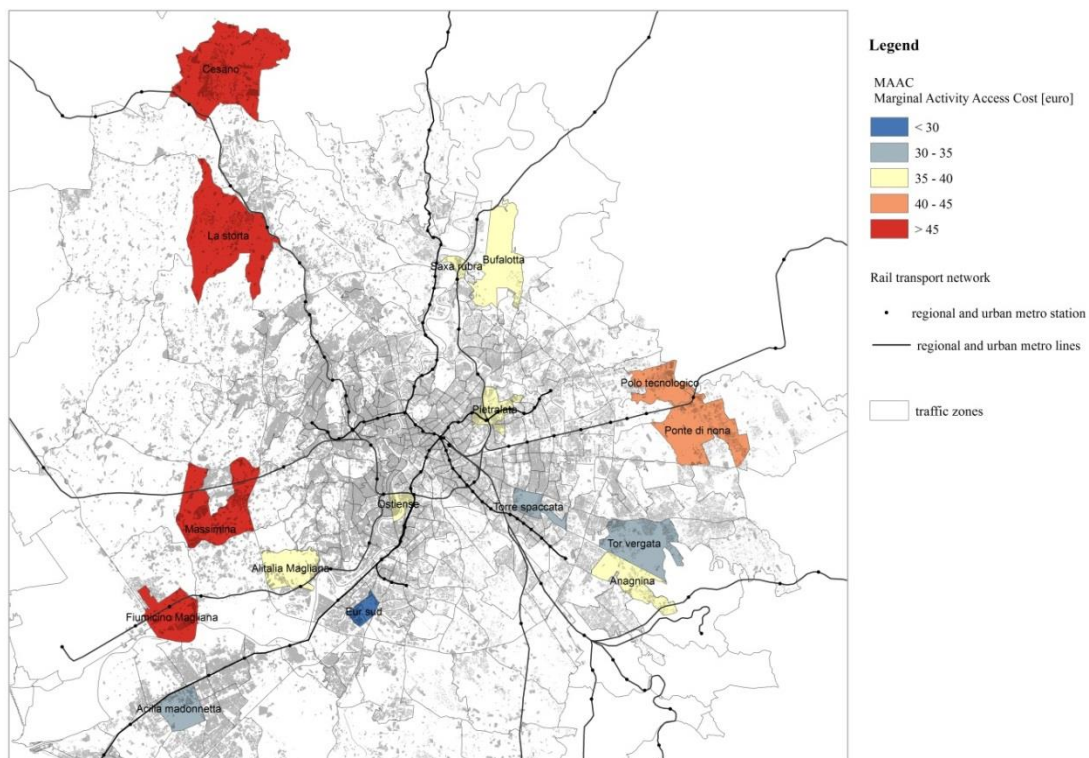


Figure 5. Average values of MAAC for the new “centralities” defined by the Master Plan of the Municipality of Rome

The MAAC values for the “centralities” allow to validate the location choices proposed by the Master Plan, from the perspective of the impacts on transport cost and related externalities. As can be seen from Table 4, the “Tor Vergata” and “Eur Sud” centralities proposed in the Master Plan present lower MAAC values than other peripheral centralities. Among the latter, Fiumicino-Magliana, Cesano and La Storta, are so far from urbanized area as to have very high MAAC, especially for the External Transport Costs (ETC) component. These seem to be not sustainable locations for new settlements.

Table 4. Average values of MAAC (induced mobility costs IMC plus external transport costs ETC) for new Master Plan Centralities

Master Plan new centralities	IMC component	ETC component	AAC
	(a) [€]	(b) [€]	(a+b) [€]
Fiumicino Magliana	21,8	31,9	53,7
Cesano	18,6	34,0	52,6
Massimina	20,5	31,5	51,9
La storta	17,6	29,8	47,4
Polo Tecnologico	16,5	24,1	40,6
Ponte di Nona	16,0	24,1	40,1
Bufalotta	16,1	23,5	39,6
Alitalia Magliana	16,8	21,8	38,6
Saxa Rubra	15,4	21,8	37,2
Anagnina	14,8	21,6	36,4
Pietralata	17,5	18,2	35,7
Ostiense	18,4	16,8	35,2
Torre Spaccata	15,4	17,6	33,1
Acilia Madonnetta	14,0	17,7	31,7
Tor Vergata	13,7	17,8	31,4
Eur sud	14,0	15,9	29,8
Mean value	16,7	23,0	39,7

5. CONCLUSIONS

This paper proposes an aggregate (zone-specific) indicator, the Marginal Activities Access Cost (MAAC), to measure the impacts of locating new activities on transport system and related externalities. In line with the goals of

accessibility planning, aiming at sustainable and integrated Land-Use and Transport (LUT) development, this indicator is an useful tool to assess the location choices of new activities and it does represent an important step towards a more comprehensive approach to measuring and communicating accessibility changes to decision makers. Unlike the existing aggregated accessibility measures, the MAAC takes into account not only individual travel time and costs (IMC) but also external costs (ETC) and has a clear and communicable unit of measure (Euro).

An application to the urban area of Rome have been presented aiming at validating the proposed indicator through its application to zones characterized by different connectivity by public transport and different proximity to CBD. This application helped to explore the potentiality of the new indicator compared to the passive gravity-based accessibility measure. It results that proximity to city center (i.e., in the mono-centric case study of Rome, proximity to more densely urbanized districts) is a key factor in determining the MAAC: the areas close to city center present values of both IMC and ECT lower than the zones far from the city center with low density of settlements. Moreover, zones with high connectivity by public transport present MAAC values lower than those characterized by prevailing connectivity by car, due to less volume of vehicles directed towards these zones: fewer trips by car correspond to lower emissions and therefore smaller external costs.

Compared to passive gravity-based accessibility, the MAAC present a broader range of variation across zones with different proximity to city center, due to the inclusion of the external cost component, which is not taken into account by other accessibility measures.

Finally, the MAAC has allowed to assess the new location choices proposed by the Master Plan of the Municipality of Rome, identifying critical issues related to those “centralities”, i.e. Fiumicino-Magliana, Cesano and La Storta, which have so high MAAC to seem not sustainable for new settlements.

Further researches and improvements will regard the validation of the proposed measure to metropolitan areas with polycentric urban pattern in order to verify usability and transferability of the proposed tool to different urban contexts (mono-centric vs. polycentric urban areas).

6. REFERENCES

Ben-Akiva, M., & Lerman, S. R. (1979). Disaggregate travel and mobility choice models and measures of accessibility. *Behavioural travel modelling*, 654-679.

Ben-Akiva, M., & Lerman, S. R. (1985). *Discrete choice analysis: theory and application to predict travel demand (Vol. 9)*. The MIT press.

Cascetta E. (2009) *Transportation System Analysis: Models and Applications* Springer, New York

Cascetta E., Carteni A., and Montanino, M. (2013). "A behavioral indicator for cumulative accessibility to opportunities: definition and application to a real case-study" *Procedia Social and Behavioral Sciences* (forthcoming).

Coppola, P., & Nuzzolo, A. (2011). "Changing accessibility, dwelling price and the spatial distribution of socio-economic activities" *Research in Transportation Economics*, 31(1), 63-71.

Crucitti, P., Latora, V., and Porta, S. (2006) "Centrality measures in spatial networks of urban streets" *Physical Review E*, 73(3), 036125.

Curl A., Nelson, J. D., & Anable, J. (2011). "Does Accessibility Planning address what matters? A review of current practice and practitioner perspectives" *Research in Transportation Business & Management* 2, 3-11.

Dong, X., M. Ben-Akiva, J. Bowman and J. Walker (2006), *Moving from Trip-Based to Activity-Based Measures of Accessibility*, *Transportation Research Part A*, 2006, Vol. 40, No. 2, pp. 163-180.

Geurs K.T., & van Eck J.R. (2001). *Accessibility Measures: Review and Applications*. Rijksinstituut voor Volksgezondheid en Milieu (National Institute of Public Health and the Environment, RIVM) and Urban Research Centre, Utrecht University. Bilthoven/Utrecht, Netherlands.

Geurs K.T., & van Wee B. (2004) "Accessibility evaluation of land-use and transport strategies: review and research directions" *Journal of Transport Geography*, 12, 127-140.

Handy, S. L., & Niemeier, D. A. (1997). "Measuring accessibility: An exploration of issues and alternatives" *Environment and Planning A*, 29, 1175-1194.

Hansen, W. G. (1959). "How accessibility shapes land use" *Journal of the American Institute of Planners*, 25 pp. 73-76.

Hull A., Papa E., Silva C., & Joutsiniemi A. (2012). Discussion on accessibility instruments. In Hull A., Silva C., Bertolini L. (Eds.), *Accessibility Instruments for Planning Practice* © COST Office.

Kwan, M. (1998). "Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-based Framework" *Geographical Analysis*, 30 (3), 191-216.

Ingram, D. R. (1971). "The concept of accessibility: a search for an operational form" *Regional studies*, 5(2), 101-107.

Maibach, M., Schreyer, C., Sutter, D., Van Essen, H. P., Boon, B. H., Smokers, R., ... & Bak, M. (2008). *Handbook on estimation of external costs in the transport sector. Internalisation Measures and Policies for All external Cost of Transport (IMPACT)*. CE Delft.

Nuzzolo A., & Coppola P. (2005). S.T.I.T.: a system of mathematical models for the simulation of land-use and transport interactions. *Proceeding of the European Transport Conference, Strasbourg, France*. © AET and contributors 2005.

Odgaard, T., Charlotte K. & James L. (2005). *Current Practice in Project Appraisal in Europe, HEATCO - Developing Harmonized European Approaches for Transport Costing and Project Assessment, Deliverable 3*; prepared for the European Commission.

Straatemeier, T. (2008). "How to plan for regional accessibility" *Transport Policy*, 15(2), 127-137.

Uniontrasporti (2009). *Strategie d'intervento per il rifornimento delle reti commerciali al dettaglio*. UnionTrasporti, Napoli