European Transport \ Trasporti Europei (2020) Issue 76, Paper n° 1, ISSN 1825-3997

What about a different road network hierarchy? New perspectives towards sustainable mobility: the case of Thessaloniki, Greece

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Abstract

The current paper aims at creating a methodological framework for re-organizing the main road network hierarchy of a metropolitan city. It proposes a compact method for formulating an integrated functional classification that takes into consideration all individual modes of transport as well as the urban dimension of the city. This method classifies the road network into 6 categories based on position in the network, their topology, their connectivity, their urban characteristics and the existence of bus lines or cycling routes along with their current classification. The study area of the research is the city of Thessaloniki in Greece.

The implementation of the proposed methodology may benefit the city of Thessaloniki in several ways. Moreover, the aforementioned methodological approach constitutes a planning tool that provides priority sustainable modes rather automobiles. Finally, it could be applied to other study areas as well, acting as guidelines for road hierarchy re-organization.

Keywords: Road Network Hierarchy; Sustainable Mobility; Integrated urban and transport planning.

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1. Introduction

Contemporary cities face several challenges questioning their sustainability and efficiency (Jabareen, 2006). Significant share of these current problems is caused by car-oriented planning, which dominated the planning procedure in cities mainly after 1950s (Marshall, 2005). Transport systems mainly based on motor vehicles resulted in traffic congestion, inaccessible public spaces, severances to the urban fabric, road accidents and other various insufficiencies in urban areas (Mendez et al., 2017). This situation demands an effective and resilient planning perspective. Therefore cities must now embark on a process of transformation by developing strategies to counter the negative impacts of urbanization and bring prosperity to the urban environment (Aleta et al., 2017).

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Under these circumstances, a new perspective regarding cities and their future has emerged during recent years; this perspective is no other than Sustainable Mobility (Bannister, 2008). Sustainable mobility describes a system that meets transport needs through promoting public transport, walking and cycling and, at the same time, enhances environmental integrity, social equity and economic efficiency. The way towards sustainable mobility requires several steps. A basic prerequisite for achieving an adequate sustainable mobility level is the adoption as well as the implementation of a unified urban and transport planning approach (Vlastos and Milakis, 2006). One of the most fundamental components of this approach is the road network hierarchy or street functional classification (Huang et al., 2016), which organizes car-movement, thus changing urban environment and developing a discrete road network management system (Ribeiro, 2012; Plowright and Marshall, 2004; Stamatiadis et al., 2017).

In this context, the present research aims at creating a methodological framework for re-organizing the road network hierarchy of a metropolitan city. More specifically, it proposes a compact and distinct method for formulating an integrated functional classification which takes into consideration all individual modes of transport as well as the urban dimension of the city. The study area of the research is the city of Thessaloniki (Greater Area). Thessaloniki is the second largest urban area in Greece with a population of approximately 1 million residents. Regarding the hierarchy issue, it should be noted that the existing street functional classification system is mostly car-oriented, non-adequately integrated/compatible with the urban dimension of the city, thus being deficient and insufficient.

2. Street functional classification: Definitions and Perspectives

Hierarchy is illustrated to exist in many natural and social systems such as cells, cities, computer networks as well as languages (Pumain, 2006). According to Batty (2006) hierarchy is implicit in city systems, regardless if it is established or organic. Focusing on transportation, the way urban streets or roads are connected gives rise to a particular hierarchical structure (Marshall et al., 2018; Yerra and Levinson, 2005), in which the majority of streets is trivial, while the minority is vital (Jiang, 2009). Road network hierarchy defines the functional classification of roads or streets by which they are grouped into classes or systems, depending on the function they serve (Marshall, 2004). More precisely, hierarchy specifies the role of each road or street in the urban transport network (FHWA, 2013).

According to the conventional approach, roads are defined mainly by the degree to which they emphasize through movement for automobiles (mobility) versus local access (Tumlin, 2012). These two functions, mobility and access, give rise to 3 main road categories, which are arterials, collectors or distributors and local roads (Levinson and Krizek, 2008). In several cases though, these categories are either more specialized e.g. principal or minor arterial in USA and China (FHWA, 2013; Huang, 2005) or enriched with more categories e.g. freeway or motorway in Denmark and Canada (Marshall, 2002; Transportation Association of Canada, 2011). In coordination with the majority of functional classification guidelines, the Greek guidelines suggest four road categories, considering the mobility function as more important. These categories are freeways, arterials, collectors and local roads (Ministry of Environment, Regional Planning and Public Works, 2001). The aforementioned approach regards that mobility is inversely correlated with access (Plowright and Marshall, 2004), demonstrating as its basic principle the sustaining of car-movement (Jones and Boujenko, 2009). Therefore, car arterials and local streets (e.g. pedestrian) are placed at the first and the last place of the "pyramid", respectively. According to Marshall (2004, 2005) this car-oriented approach resulted in dysfunctional urban systems with environmental issues and unattractive, inaccessible public spaces. More specifically it separates road users and leads to the exclusion of pedestrians and cyclists from the streets. Furthermore, it creates movement barriers, which constitute major severances to the urban fabric and discourage active ways of movement (Hall, 2006). Liu et al. (2017) state that this car-dominated road classification has neglected the social dimension of roads and has created a transport system in which other surface modes are not adequately integrated. In addition, Greenberg and Dock (2003) argued that the guidance and design standards of the conventional approach cannot meet the requirements of sustainability. Finally, this specific classification does not allow the existence of traditional arterial streets, where both circulation and human activities take place (Svennson, 2004).

However, streets serve multiple functions and should not be designed only for automobile throughput; on the contrary, they should be vital and multimodal places (Tumlin, 2012). Therefore a new hierarchy planning that promotes sustainable and active means of transport such as public transport, walking and cycling is more compulsory than ever (Rychlewski, 2016). Such hierarchy has to propose the radical transformation of the road from a traffic conductor to a communication and interaction space, an environment where different modes and different speeds co-exist (Marshall, 2005). Notable research has been done towards this direction, highlighting the necessity of an alternative functional classification facilitating sustainable mobility (Wang et al., 2018). For instance, Marshall (2006) proposed the adoption of a transit oriented hierarchy, which gives priority to public transport and enhances the cooperation between sustainable modes of transport. In addition, Strate et al. (1997) conducted a study designing functional classification for a multimodal transport system and the City of Portland suggested that a thoroughfare's primary function could be established as either vehicle or pedestrian mobility (or bike or transit), thus formulating an integrated approach (Hall, 2006). Moreover, a significant number of scientific papers and technical guidelines adopted a matrix-based approach of classification which takes into consideration both "Link" and "Place" functions (e.g. Ribeiro, 2012; Svennson, 2004; Jones et al., 2008). Finally, Liu et al. (2017) proposed a three-dimension functional classification system which is based on Hierarchy, Activities and Mode, constituting an innovative solution in urban transportation field. The aforementioned papers mention extensively that the future of transport systems should be integrated and based on a new and innovative hierarchy; one that will be inclusive and accessible for all.

3. Methodology

The methodological framework consists of three distinct steps. The first step defines the overall vision towards the new hierarchy of the transport network. The central objective of the new functional classification is to promote sustainable means of transportation along with limitation of car usage, as well as to enhance the readability of the road network. The second step, consisting of two parts, analyses the study area in order to identify its potentials. The first part concerns the urban characteristics of Thessaloniki as well as the identification of the major urban centers. Road segments of the existing main road network are divided into two categories regarding their urban dynamic, either "Road with high interest" or "Road with low interest". Land uses, streetscape characteristics, such as pavement width and total road width and the intensity of human presence have been qualitatively examined and combined to compose the urban "interest" of each road. Central areas are classified into two categories (metropolitan or inter-municipal) according to the General Land Use Plans of the municipalities of Thessaloniki. The second part investigates the main transport networks of the city. We examined the current classification, the existing bus and cycling routes, in order to obtain a comprehensive view of the existing transport system. After this process, in the third step we formulated the proposed strategic road network which simplifies the geography of routes, defines the city's main connections and their role (i.e. car or sustainable modes priority route), establishes road rings utilizing the existing road segments as well as protects the principal urban centers by deterring vehicular through traffic. Regarding this protection, we suggest the creation of environmental cells and low-intensity car use zones (buffer zone of 300m around each center), where priority to private vehicles is neglected. Finally, the result of the methodological procedure is a new functional classification of the strategic road network of Thessaloniki.

The classification system is based on two dimensions, coordinated with innovative approaches (Marshall, 2006; Jones, et al. 2008), differing from the conventional one-dimension system. The first dimension concerns the division of the main network into 2 groups according to their significance; the primary road network of strategic significance and the secondary road network with intermunicipal significance. Criteria used for these categories are the road's connectivity (meaning, if connects central areas), the geography (meaning, the position in network) and the current classification of the road network. The second dimension separates these groups in three individual categories. Criteria used are the urban characteristics of roads, the existence of bus and cycling routes as well as the geography of road segments. We utilized two tools for the re-classification of the city's main road network: (1) an indicator depicting the potentials for sustainable means of transport and (2) the algorithm of shortest path in a given network. The former is composed by the combination of urban characteristics and the existence of bus and cycling routes. Specifically, we divided the main road network into 4 categories, regarding their potentials for facilitating sustainable modes of transport, either "High" or "Medium" or "Low" or "Negligible". The latter includes the use of the "v.net.allpairs" tool in GRASS GIS which computes the shortest path between all pairs of nodes, major urban centers in particular, in a given network. This tool links two centers with one route, enhancing the robustness of the proposed network (Friedrich, 2017). According to the proposed methodology, the strategic road network consists of 6 categories, which can be applied to other metropolitan cities as well. These categories are shown below (Table 1):

Table 1: Road network categories

Category		*Code*	*Symbol*	*Indicative Policies*
Significance	*Priority*			
Primary (strategic)	car	1A		• Speed up to 90km/h • Elevated or signalized junctions, no left turns, 2 or 3 lanes for car circulation • Minimum design for active users • Public transport • On-street parking prohibited
	mixed	1B		• Speed up to 60-70km/h • Tram or BRT, signalized junctions, 2 lanes for car circulation • Cycling routes (separate infrastructure), enough space for pedestrians, enhancement of urban identity • On-street parking prohibited
	sustainable modes	1C		• Speed up to 50km/h • Tram or BRT, signalized junctions, 1-2 lanes for car circulation • Cycling routes (separate or roadway infrastructure), enough space for pedestrians, enhancement of urban identity, more crosswalks, promotion of pedestrian-friendly land uses • On-street parking prohibited
Secondary (inter-municipal)	car	2A		• Speed up to 60-70km/h • Signalized junctions, 2 lanes for car circulation • Minimum-Medium design for active users • Public transport • On-street parking prohibited
	mixed	2B		• Speed up to 50-60km/h • LRT or simple bus (frequent), signalized junctions, 1-2 lanes for car circulation • Cycling routes (separate or roadway infrastructure), enough space for pedestrians, enhancement of urban identity, promotion of pedestrian-friendly land uses • Limited on-street parking under circumstances
	sustainable modes	2C		• Speed up to 50km/h (mainly 30km/h) • LRT or simple bus (frequent), signalized junctions, 1 lane for car circulation • Cycling routes (separate or roadway infrastructure), enough space for pedestrians, enhancement of urban identity, more crosswalks, promotion of pedestrian-friendly land uses • Limited on-street parking under circumstances

First three categories are part of the primary road network. One criterion for whether a road belongs to this group is connectivity. Connectivity identifies the centers that are connected with the particular roadway (Stamatiadis, et al., 2017). All the roads in these categories should either formulate a Ring Road of the city or connect the metropolitan center to other extra-urban centers. Other criteria are the road's geography, where the road ought to cross or to be part of the outer ring road. In other words, the primary network functions as a link between the metropolitan and regional areas. Another critical factor is the geometry of this network; it consists of radial or circular routes, facilitating movement in a metropolitan level. The roads that meet these criteria are then divided into three individual categories, as shown at the table 1. The principal criterion used for this categorization is the roads' geography; road segments outside the ring road of the city prioritize car movement, road segments inside the metropolitan ring road but outside city center's ring road prioritize both car and sustainable modes and finally road segments that belong to inner ring road area prioritize sustainable means of transport. Furthermore, this specific network is contiguous demonstrating the principles of arteriality (Marshall, 2005).

The first category (1A) prioritizes the movement of private vehicles. Roads in this category connect the metropolitan center to outer urban areas or function as ring roads for diverging traffic and thus forming the strategic ring road of Thessaloniki. Subsequently, these roads form a circular route around the city along with radial routes towards the city core and the greater metropolitan area, demonstrating unstimulating urban characteristics. The second category (1B) is addressed equally to all means of transport; private vehicles, public transport and other sustainable modes have almost equal priorities. In order for a road to fall into this category, it is examined on the basis of its geography. These streets form a transition zone with radial and circular routes around the metropolitan center. Category 1B consists of roads inside the outer Ring Road and outside the ring road around the urban core. It has to be noted that the city center's ring road belong to this group. The next category (1C) gives priority to sustainable means of transport enhancing public transport, cycling and walking. It consists of readable, radial routes with notable urban interest and lower speed limits that belong to the city core of Thessaloniki.

The next three categories constitute the secondary road network which aims to facilitate movement inside the principal ring road zone of Thessaloniki. Therefore, a road with intermunicipal significance connects the municipal centers with each other or with the metropolitan center, and it functions as an intermediate link for the primary network. Criteria for splitting the secondary road network into 3 individual categories are the variety of urban characteristics and the existence of main bus or cycling routes on the road; roads that meet those criteria are recommended to sustain public transport and other sustainable modes. This group includes roads that are suggested by the shortest path algorithm (v. net. allpairs), where we aim to extract a route addressed to sustainable modes of transport and one addressed to private vehicles.

The fourth category (2A) is addressed to private vehicle movement and roads aim to connect the city centre with intermunicipal centers or connect municipal centers to each other. Category 2A consists of roads connecting the secondary road network to the primary road network, as well as radial and circular routes around the metropolitan center. These roads cannot be inside the environmental cells of municipal range, nor in the 300m buffer zone around the municipal centers (low intensity car use zone). Selection of roads that constitute 2A is based on the shortest path algorithm and the combinatorial indicator is used as the cost value. Moreover, the presence of cycling and bus routes adds numeric value to the cost of a road which means that the more urban characteristics it possesses, the higher is the value added to the road's cost. Roads indicated by the algorithm that do not belong in the municipal ring roads are labeled as 2A. Category 2B of the secondary network is addressed equally to all means of transport; Roads connect the city centre with other municipal centers or connect municipal centers to each other, formulating a plethora of intermediate ring roads inside the city. It consists of radial or circular routes with significant urban characteristics and gives the potential to contain roads which pass through environmental cells or the low intensity car use zones. The roads classified as 2B are the intersection of the results from the application of the shortest path algorithm regarding the categories 2A (as already presented) and 2C. Category 2C has similar characteristics to 2B, but it orients towards public transport and cycling; It consists of radial routes with significant urban characteristics, connecting one municipal center to another. These roads may be both inside and outside environmental cells or low intensity car use zones. The shortest path algorithm is used in the inverse way of the case in category 2A; absence of urban characteristics, cycling and bus routes are high cost values. In other words, roads with various urban characteristics and public transport infrastructures are planned to prioritize sustainable modes of transport.

4. Study area and Results

The study area is the city of Thessaloniki, which constitutes the second largest city in Greece with almost 790.000 inhabitants in its urban area and over 1 million in its metropolitan area, according to the last census in 2011. It is located on the Thermaic Gulf, at the northwest corner of the Aegean Sea and is bound by Mount Chortiatis on its southeast, covering a land area of 111.703 km². It consists of six municipalities (including the municipality of Thessaloniki) and the municipal unit of Pylaia, forming the urban core of the Thessaloniki Greater Area.

The current road network classification of Greater Thessaloniki is undoubtedly car-oriented, allowing the penetration of the main core by major arterials and undermining the significant role of sustainable means of transport. Apart from the existence of the Metropolitan Ring Road (approximately 63km) that contributes to the diversion of regional through traffic, the road network does not include ring roads of intermunicipal or local significance, even a discrete ring road protecting the primary center of the city. Hence, it is striking that a great share of traffic flow is passing by through the main urban core of Thessaloniki as well as through numerous neighborhoods, resulting in unfavorable conditions regarding pedestrians and vulnerable social groups. Moreover, the "chaotic" form of the main road network does not achieve intelligibility and efficiency while it creates serious movement barriers to the urban fabric (Figure 1a).

The proportion of the main road network in the entire city's road network is approximately 26% (primary roads and motorways are 5% each, secondary roads are 9% and tertiary roads are 7%), meaning that a significant number of roads is dedicated in facilitating motor vehicles circulation. The insufficient state of the current road network classification, which is incapable of promoting sustainable mobility, requires crucial changes. In this context, we identified the existing potentials of the road network for facilitating sustainable modes of transport. Only 10% of the main road network has "high" or "medium" potential to bring sustainable means of transport to the frontline; on the contrary most of the existing main road network does not meet the proper requirements, thus highlighting the urgent need for efficient planning solutions.

Taking into account the proposed methodology as well as the identified shortcomings of the case study, we formulated a new functional classification system which re-establishes the strategic road network of the city, aiming towards sustainability, intelligibility and efficiency (Figure 1b).

This new classification re-addresses the priority of the individual transport modes composing a entirely different road network hierarchy. Specifically, 6% the primary road network prioritizes sustainable means of transport, 40% is characterized by a mixed-priority state and 54% provides priority mainly to automobile. As for the secondary road network, a percentage of 30% turns into sustainable modes, 47% combines private vehicles and sustainable means and only 23% prioritize car circulation. The aforementioned signify that the absolute car dominance has been reduced by 36% and 77% respectively. Furthermore, the new strategic road network constitutes only 7% of the whole road network (89,2km), depicting a 19% reduction which can ensure readability and proper management of the network. In overall terms the road network examined and reclassified is 46% of the total segments in Greater Thessaloniki.

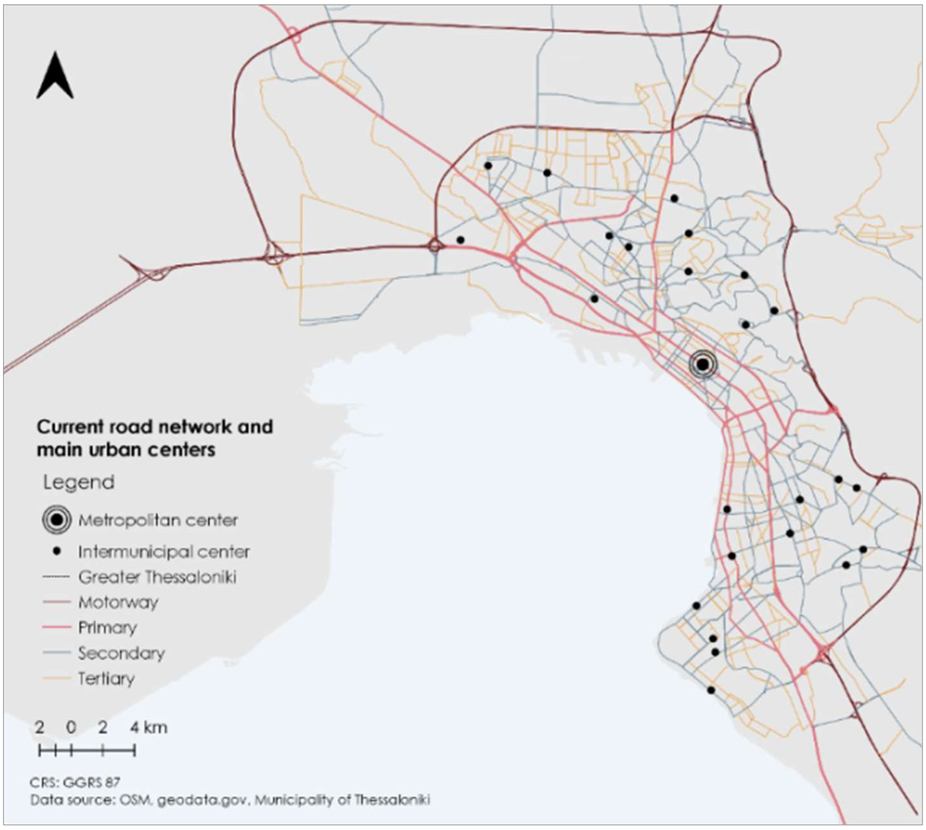

Figure 1(a): Current functional classification of road network and main urban centers

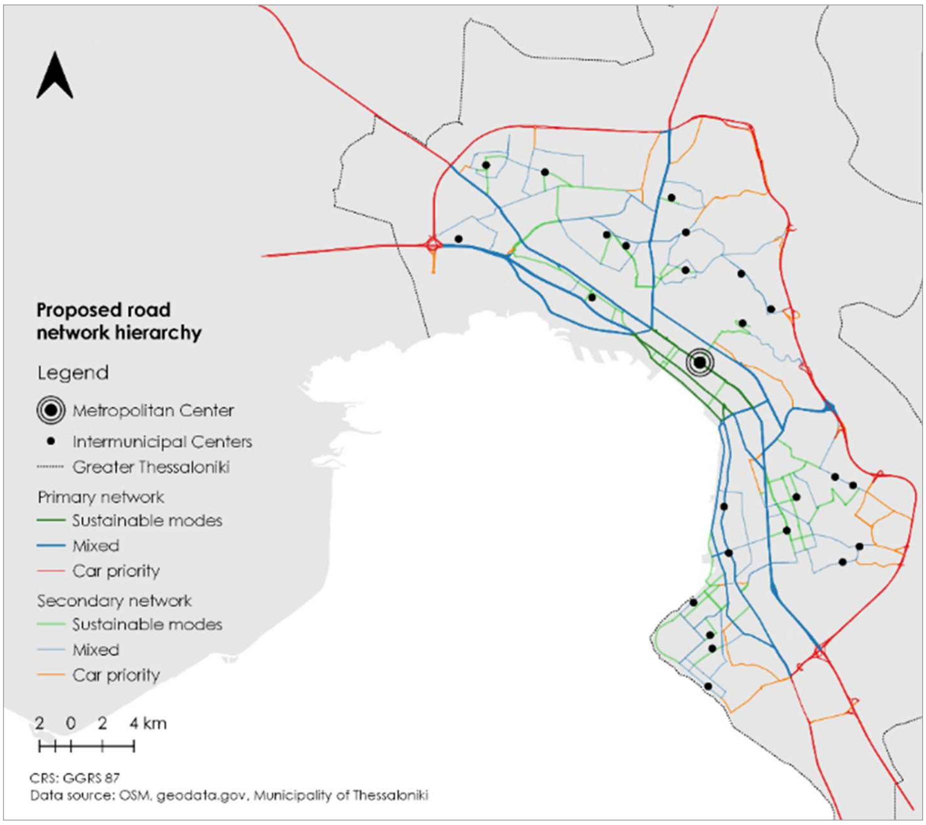

Figure 1(b): Proposed functional classification of road network-new strategic road network

Moreover, the new classification system formulates 16 low intensity traffic zones (including the metropolitan center zone) which protect central areas of the city from through traffic. These areas cover 8% of the area inside the Main Ring Road of Thessaloniki, creating the conditions for promoting active transportation modes (cycling, walking, and micromobility). The new classification system achieves a balanced situation between circular and radial arterials, due to the fact that the ratio of beltness (Length of beltways/Total length of arterials) (Xie and Levinson, 2007) is approximately 46%. The new hierarchy of the city suggests the creation of 51,2 km of strategic roads dedicated to sustainable mobility, while the current classification has not such a regulation. Finally, the plan of functional classification unifies the urban fabric of Thessaloniki by re-addressing 96,4 km of arterials facilitating primarily car-movement to arterials which enhance human presence and interaction. All aforementioned assessment tools are summarized in the table below.

Table 1: Assessment tools examined

Indicator	*Value*
Increase of roads dedicated to public transport	51.2 km
New main road network in the study area	7%
Ring roads’ zones covering the study area	8%
Eliminated traffic barriers	96.4 km
Ring roads / Radial roads	0.89

5. Conclusions

This paper introduces a methodological tool for re-organizing the strategic road network hierarchy of a city and proposes a functional classification system that is sustainable-oriented, human-centered and evidence-based. The proposed methodology is constructed for an urban area with a population of approx. 1 million residents and an area of 111.703 km², so it concerns cities with similar size and significance. We put forward an integrated and unified approach that takes into account the transportation and urban/land-use characteristics of the network. Specifically, we suggest a two-dimensional matrix approach that addresses the priority, which accounts for the promotion of sustainable modes of transportation, and the significance, accounting for the position of each road segment in the whole network, and provides a comprehensive methodological proposition in the road network classification issue. It is explicit that an even more detailed methodological approach could include additional characteristics such as geometrical road characteristics, type of intersection, modes of regulation and profile transverse. Though, two key aspects of the urban fabric are utilized: connectivity, meaning the property of the network to connect central areas, which is crucial for a polycentric urban form, and the continuity in all strategic routes, not exclusively for cars but for all means of transportation (e.g. walking, micromobility, cycling, and public transportation). What is more, we propose a method for formulating environmental cells or low-intensity car use zones where car cannot penetrate and priority to private vehicles is neglected. The proposed methodology as applied in the Greater Thessaloniki area achieves a simple, readable and intelligible network and a balanced situation between circular and radial arterials thus minimizing the current dominance of radial networks. Moreover, we suggest indicative policies for the study area of Thessaloniki, which bridge the gap between planning theory and practice.

The current research, introduces a new approach in road-network hierarchy a subject which is considered fundamental in urban and transportation planning and therefore provides significant value. We propose a straightforward methodology that could function as a decision support tool for the transportation and urban planning process and could be replicated in other cities with similar characteristics. Probably, the most important achievement of this paper is that despite any shortcomings that may arise in implementing such strategy, the rationale introduced here should influence the existing institutional aspects of urban and transport planning procedures.

Tellingly, the proposed functional classification is focused on the metropolitan level and therefore designates the strategic network. Roads with local importance are not included in our methodology as they require different analysis and overall approach. In other words, a crucial research step moving forward, is the conceptualization of a functional hierarchy methodology which would focuses on the local spatial level e.g. municipality and would define the road network with lower significance such as collectors, traffic calming streets, pedestrians etc. In such level (local) the “potentials for sustainable mobility” criterion could include additional factors such as walkability features (e.g. sidewalk width), streetscape design characteristics, etc. A crucial component of the proposed functional classification of the strategic road network is the integration of a network analysis tool (v.net.allpairs) in the methodology and the utilization of more evidence-based tools and methods in further research of this issue could inform and advance even more the methodological process. Finally, the connection of the subject of road network hierarchy with innovative technologies and data sources (e.g. crowdsensing, mobility data and activity data) in general, would be a substantial contribution in this particular issue of transportation planning.

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