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The Role of Road Hierarchization in Development of Transport Infrastructure in Urban Areas and Its Links to Urbanism

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Abstract

The hierarchization of roads plays a crucial role in the development of transport infrastructure in urban areas. Roads in urban areas can be described in a dualistic manner: as conductors of traffic (transport-engineering aspect) and as structures mirroring functions of the city (urbanistic aspect). However, few methods explore this dualistic characteristic, and so the hierarchization of roads is usually based solely (mainly) on the transport-engineering aspect. This paper discusses the importance of the dualistic characteristic and introduces a hierarchization method based on both aspects. The results of this study could contribute to our practical and intuitive understanding of the effects of transport on the development of cities and on other topics related to transport/urbanism.
KEY WORDS: *transport-engineering aspect, urbanistic aspect, hierarchization methods, transport infrastructure*

1. Introduction

Roads and, by extension, road networks are crucial elements of a city infrastructure. They play a key role in the transport accessibility of a city, and as such, roads are often described regarding their ability to conduct traffic (both passenger and freight). This traffic-oriented description of the road infrastructure can be labelled as a transport-engineering aspect. However, the transport-engineering aspect defines roads only partially, as the roads are dualistic in function. The second aspect of the definition of roads can be labelled an urbanistic aspect. The urbanistic aspect mirrors the functions of a city and projects them into the structure of the road itself. For example, a road in an attractive tourist area with many restaurants, cafes, etc. can incorporate this principle by creating space for outdoor seating areas, small plazas, parklets, and other pedestrian areas where people can stay (the road mirrors the commercial and tourist function of the city). Another example would be a road in a traffic calming zone. The structure of the road can mirror the residential function of the city by promoting the importance of pedestrians and allowing children's play activities in the area of the road. In some cases, the urbanistic aspect can be dominant. For example, pedestrian zones should connect important urban districts and areas and should be planned according to pedestrian routes (transport-engineering aspect of pedestrian transport). However, this is not always the case, and the urbanistic aspect may dominate the street in favour of an urban expression of the public space.

It is important to note that in this paper the terms road and street are used interchangeably. The authors of the paper argue that this is necessary to fully describe the relationship between road infrastructure and urbanism. The entire street profile should be evaluated when incorporating changes in the road structure or during the application of a road hierarchization process.

Road hierarchization is an important part of the road network analysis, as it enables one to assess the current state of the network and to propose adequate transport measures. Hierarchization methods are usually based primarily on the transport-engineering aspect, and the urbanistic aspect plays only a secondary role. The authors of the paper suggest that the urbanistic aspect should not be omitted or mitigated. On the contrary, it should be treated as an equivalent factor, and the road hierarchization process should be run in two separate instances. Thus, creating a conflict between the transport-engineering and urbanistic aspect. This conflict can be used to further deepen the road hierarchization process and can lead to a more accurately described road network.

The paper is based on the master's thesis of the first author [1]. Because of this, the paper delves mainly into the hierarchization methods used in the Czech Republic. However, the use of the new method presented in this paper is not limited to the Czech Republic. Some degree of adjustment may be necessary, but the main principle is universally applicable.

2. Analysis of the Current State

The basis for the transport-urbanistic assessment of roads in urban areas in the Czech Republic is currently the Czech technical standard CSN 73 6110 Design of urban roads [2]. The standard deals extensively with the issue of urban roads and, among other things, defines an approach that serves to divide urban roads into four functional groups:

- Arterial urban roads with mobility function (A)

- Collector urban roads with mobility and accessibility function (B)
- Local urban roads with accessibility function (C)
- Urban roads with mixed traffic (D1)
- Urban roads that are inaccessible to motor vehicles (D2)

Urban roads are grouped according to their attributes. These attributes include the extent of the transport functions (mobility and accessibility function) and non-transport functions (especially residential function), the traffic behaviour of the traffic participants, and the profile/structure of the street. In general, it can be stated that function groups categorize urban roads by their transport-urbanistic role in a specific road network. Therefore, they can be treated as hierarchical groups that determine the importance of a defined set of urban roads.

The method of CSN 73 6110 [2] defines the characteristic application of functional groups and the characteristic features of the urban roads included in the individual functional groups. The boundaries of functional groups partially overlap and, therefore, the method leaves enough room for intuitive assessment, which is based on perception of characteristics, knowledge of a specific road network, and the ability to provide expert evaluation. The functional groups serve as a baseline for the proposition of structural elements of urban roads. In relation to functional groups, traffic quality levels are also defined, which are directly related to a road capacity and determine whether a traffic flow is free, saturated, or supersaturated.

Alternatively, the method contained in the technical requirements TP 131 [3] can be used. This method does not operate with function groups but introduces the index of transport importance. The index of transport importance can theoretically take values in the interval <0,2; 62> [3], where the upper limit signals the most important roads, and the lower limit means roads of limited importance. For example, a highway could take a value of approximately 55, while an arterial road value of 15 and a local road value of 2. The importance of roads based on this index can be understood as a quantified hierarchization. This approach makes it possible to perceive the importance of individual roads at a lower level of distinction without the need to introduce a significant number of hierarchical groups. The index of transport importance is expressed as the product of individual subindices. The description of these subindices is given in detail directly in TP 131 [3].

- Subindex of road class (I_t)
- Subindex of transport significance (I_D)
- Subindex of current traffic intensity (I_{SDI})
- Subindex of prospective traffic intensity (I_{VDI})
- Subindex of importance of the mobility function (I_{VDF})
- Subindex of function conflict (I_{SF})

3. Construction of the New Method

The method proposed in this paper is based on two principles:

1. The duality of roads in urban areas is an essential concept of the proposed method and is crucial at all levels.
2. The proposed method can be divided into two processes. The first is a quantified hierarchization similar to the approach of TP 131 [3] and the second is group assignment similar to the method of CSN 73 6110 [3].

However, this approach creates two problems that make the proposed method not easily applicable. These problems need to be addressed.

3.1 Problem 1 – Conflict Between the Urbanistic and Transport-Engineering Aspect

Both of the mentioned methods incorporate the idea of the urbanistic aspect, but the role of this aspect in the process of hierarchization is ultimately diminished in favour of the transport-engineering aspect.

The method of TP 131 [3] incorporates the urbanistic aspect in the form of the subindex of function conflict (I_{SF}). However, the index of transport importance, which is crucial for the hierarchization process, is the result of the product of its subindices, which means that the urbanistic aspect is no longer distinguishable from the transport-engineering aspect and vice versa. The result of this merger may be called an universal aspect of transport importance. The universal aspect is more manageable, as there is no need to evaluate the road network two times. On the other hand, it completely removes the concept of duality from the hierarchization process. It is important to note that the structure of the subindex of function conflict itself is not adequate for road hierarchization in urban areas (see Problem 2 – Subindices of TP 131). The character of the subindices implies that the method is more inclined towards the transport-engineering aspect. Traffic intensity, road class, transport significance, and mobility function are all transport-engineering oriented attributes. It can be argued that the subindex of importance of the mobility function could also indicate the importance of other functions, as the mobility function with low importance could indicate accessibility or residential function with high importance. However, the method does not operate on this principle and a low value of the subindex of importance of the mobility function simply lowers the overall transport importance.

The urbanistic aspect is also reflected in the method of CSN 73 6110 [2]. However, the method of CSN 73 6110 is deliberately ambivalent. This is due to the functional groups and their characterization. The method implies that the functional groups C, D1, and D2 have some degree of importance in terms of the urbanistic aspect, but it is never clearly stated. Due to the ambivalence mentioned, the method functions more as an intuitive tool and gives more freedom to urban planners and their expert evaluation. On the other hand, the ambivalence makes the distinction between the transport-engineering aspect and the urbanistic aspect impossible. It can be noted that the ambivalence causes a similar result as in the case of TP 131 – the traffic-engineering and urbanistic aspects are merged and the hierarchization process is run according to the universal aspect.

Neither of the mentioned methods distinguish between the transport-engineering and urbanistic aspect. However, the proposed method, which is based on the methods of CSN 73 6110 0and TP 131, is related to the duality of roads. This incompatibility can be rectified by separating the subindex of function conflict from the index of transport importance. Separated subindex of function conflict is called index of urbanistic importance (I_{UV}) and the original index of transport importance without the subindex of function conflict is called index of transport-engineering importance (I_{DV}). This separation not only creates a foundation for the dualistic hierarchization process, but also creates the second problem.

3.2 Problem 2 – Subindices of TP 131

In the case of the second problem, it is necessary to mention that the primary use of the TP 131 [3] method is the assessment of the transport importance of roads in nonurban areas (this is also evident from the structure of the subindices). Within the urban area, the method is limited to the roads that start and exit in a nonurban area and only transit through the urban area (transit parts of roads). Of course, the method can also be used for a general assessment of roads in urban areas, but in such a case there is a rather significant risk of biased results. Therefore, individual subindices must be adjusted to the situation in an urban area. This is, of course, also true for the index of urban importance.

Subindex of road class – According to the TP 131 method [3], roads can be classified into one of the ten defined classes - see Table 1.

Table 1
Road classes and values of subindex according to the TP 131 [3]

Road Class	Index I_t [-]
I. class highways	1,5
II. class highways	1,3
I. class roads	1,0
Transit parts of I. class roads	0,9
Urban roads incorporated into the BRS	0,8
II. class roads	0,7
Transit parts of II: class roads	0,6
III. class roads	0,5
Transit parts of III: class roads	0,5
Other urban roads	0,4

The influence of the road class is recommended to be maintained within the proposed method. However, the categorisation contemplated by TP 131 (2) is inadequate for urban roads hierarchization. The category of urban roads incorporated into the Basic Road System (BRS) is especially problematic. It is not appropriate for the BRS to be an input to the hierarchization process but should instead be one of the potential outputs. Furthermore, it is not necessary to assess roads in a nonurban area, therefore, it is required to assess only the transit parts of the roads in question. The existing assessment also lacks the category of arterial urban roads, which play a specific role in the urban road system. For these reasons, the authors of the article propose a modification along the lines of Table 2.

Table 2
Road classes and values of subindex according to the proposed method

Road Class	Index I_t [-]
Arterial urban roads	1,2
Transit parts of I. class roads	1,0
Transit parts of II. class roads	0,8
Transit parts of III. class roads	0,6
Other urban roads	0,5

Subindex of road significance – except for omitting the category of other selected road network (the range of this road network is no longer monitored – a specific category for the Czech Republic), this subindex can be used without modifications.

Subindex of current/prospective intensity – the subindex of current/prospective intensity is based on the annual average traffic intensities measured in the national traffic count [3] and divides roads into nine categories (see Table 3). The TP 131 method [3] assumes the use of only one lane with the highest intensity; to avoid causing too much distortion of the results, when comparing two-lane and multi-lane roads, it is preferable to consider the highest intensity of one of the entire directions [4]. The same values are used for both current and prospective intensities. In other regards, the subindex is valid as is, but it could be theoretically transformed into more intuitive measurement based on qualitative assessment of current traffic flow.

Table 3
Categorization of traffic intensity according to the TP 131 [3]

Category and Intensity	Index $I_{SDI/VDI}$ [-]
I. more than 30 000 vehicles/24 h/lane	5,0
II. more than 20 000 vehicles/24 h/lane	4,0
III. more than 15 000 vehicles/24 h/lane	3,4
IV. more than 10 000 vehicles/24 h/lane	2,8
V. more than 5 000 vehicles/24 h/lane	2,0
VI. more than 2 500 vehicles/24 h/lane	1,5
VII. more than 1 500 vehicles/24 h/lane	1,3
VIII. more than 500 vehicles/24 h/lane	1,1
IX. 0-500 vehicles/24 h/lane	1,0

Subindex of importance of the mobility function – the subindex divides roads into five category groups labelled *a-e* according to the importance of the mobility function. The category groups have the following subindex values:

- Category group *a* – value of 1
- Category group *b* – value of 0,9
- Category group *c* – value of 0,8
- Category group *d* – value of 0,6
- Category group *e* – value of 0,4

The definition of the subindex according to TP 131 [3] creates two problems when using this method in urban areas. First, the entire spectrum of categorization cannot be used, as the category group *a* is defined only for roads in nonurban areas (and without transit parts of those roads). Second, a holistic assessment of the road network in urban areas requires a lower level of distinction. Due to the mentioned problems, the authors of the article propose a scale assessment (see Fig. 1). In this approach, the value of 0,4 signals a high importance of the residential function, and value of 1 signals a high importance of the mobility function. The value of 0,6 is interpreted mainly as an accessibility function with residential function potential.

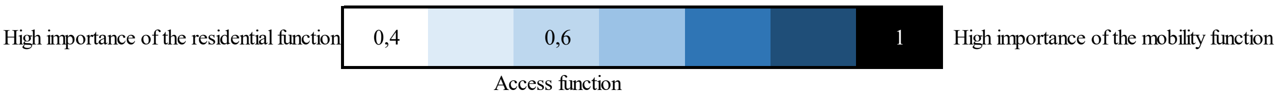

Fig. 1 Scale assessment of the index of importance of the mobility function

Index of urbanistic importance – method of TP 131 [3] describes the index as a representation of the conflict between the mobility function and one other function that is defined by the method (see Table 4).

Table 4
Function conflict and index values according to the TP 131 [3]

Conflict of the mobility function with	Index I_{SF} [-]
Direct accessibility function (nonurban areas)	1,05
Direct accessibility function (urban areas)	1,1
Public transport stops	1,15
Pedestrians or bicyclist's routs	1,2
Busy commercial street	1,25
Residential function, tourist function, etc.	1,3
No conflict	1,0

Function conflict limited to only two functions is appropriate for nonurban areas, where functions can be identified and separated [4]. However, the merging of two and more functions is characteristic for urban areas, and so this principle fails in implementation. The categorization itself is adequate for use in urban areas, nevertheless, the authors of the article propose a modified categorization which is more linked to city functions (see Table 5). Some of the categories should be assessed with a range that allows one to define the intensity of the parameter. In the proposed method, the index of urbanistic importance is a result of the sum of its subindices:

- Transport function with parameter of motor transport (FD_{IAD}) – motor transport and especially private transport is dominant, routes of public transport and/or bicycle and pedestrian transport are non-existent or insignificant (in case this is the only function that was applied). Can be combined with the function FD_{HD} and/or $FD_{C/P}$.
- Transport function with parameter of public transport (FD_{HD}) – road is important from the point of view of public transport – routes, stops, preferential measures, etc. are part of the street. Can be combined with the FD_{IAD} and/or $FD_{C/P}$.
- Transport function with parameter of bicycle and pedestrian transport ($FD_{C/P}$) – road is important from the point of view of bicycle and pedestrian routes; there may be a significant volume of pedestrians and cyclists that interact with motor traffic.
- Transport and access function towards industrial facilities (FP)
- Residential function (FO) – street is characterized by residential and accessibility function and may be part of a traffic calming zone.
- Transport and accessibility function towards civil amenity facilities (FOV) – schools, libraries, administrative facilities, hospitals, theatres, etc. are vital parts of a city infrastructure and create specific transport demand. Civil amenity facilities are also an important part of city space and, as such, are valuable from an urbanistic point of view.
- Transport and accessibility function towards recreational and tourist targets (FR) – important function near parks, plazas, squares, etc. The road itself should be also considered as a potential recreational/touristic target.

Table 5

Function conflict and index values according to the proposed method

Urbanistic function type	**Index [-]**		
Transport function with parameter of motor transport	FD_{IAD}	1	Or 0 in the case of non-existent function
Transport function with parameter of public transport	FD_{HD}	1,15-1,3	
Transport function with parameter of bicycle and pedestrian transport	$FD_{C/P}$	1,15-1,3	
Transport and access function towards industrial facilities	FP	1,1	
Residential function	FO	1,2-1,3	
Transport and access function towards civil amenity facilities	FOV	1-1,2	
Transport and access function towards recreational and tourist targets	FR	1,2	

3.3 Creating Hierarchical Groups Within the Proposed Method

The quantified nature of the modified TP 131 method is suitable for the specific assessment of individual roads and for the detailed analysis of the observed network. However, this "fluid" hierarchy lacks clarity and is time consuming when creating outputs. Adequate measures would have to be defined for each discrete value that can potentially be achieved in the interval of the modified TP 131 method. It is more time saving to group roads into similar hierarchical groups based on their transport-engineering/urbanistic importance. This part of the proposed method is inspired by the functional groups of CSN 73 6110 [2]. In the proposed method, a set of hierarchical groups is defined for both the transport-engineering and urbanistic aspect. Individual roads are grouped according to the value assigned to them by the modified TP 131 method: For each hierarchical group, an interval is defined that decides whether a particular road will/will not fall into a particular hierarchical group. For example, hierarchical groups may be defined as follows:

- I. transport-engineering hierarchical group $\langle 1.5; \infty)$
- II. transport-engineering hierarchical group $\langle 0,8; 1,5)$
- III. transport-engineering hierarchical group $\langle 0,4; 0,8)$
- IV. transport-engineering hierarchical group $\langle 0; 0,4)$

In general, it is not possible to determine how to set the intervals for each hierarchical group. This needs to be assessed individually for each network under consideration, as the proportional range of each hierarchical group will be different for different cities.

The number of hierarchical groups should be the same for both aspects. This will also make it possible to determine the dominance of one aspect over the other and the strength of this dominance. If, for example, a road is classified in the highest hierarchical group in terms of transport-engineering aspect and in the lowest hierarchical group in terms of urbanistic aspect, it can be concluded that the transport-engineering aspect strongly dominates the urbanistic aspect. The dominance does not imply that the dominated aspect should be suppressed, but only establishes its lower priority. It may also be the case that a road is ranked in equally important hierarchical groups in both aspects. In such a case, it is necessary to balance the two aspects, as they are in direct contradiction, and neither is a priority.

4. Discussion

The perception of transport infrastructure solely on its ability to conduct traffic may not be holistic and conceptualized, as transport infrastructure should also be perceived as an urban element. The transport infrastructure in urban areas is a substantial part of public spaces, and transport itself is intertwined with a city structure and its other functions. The definition of transport infrastructure should consider not only the transport engineering aspect but should be broad enough to describe the infrastructure as a part of a sociologically and urbanistically complex issue of public space design. The links between transport infrastructure and urbanism allow for the close interaction of infrastructure and public space.

This definition should be reflected in the road hierarchization process, as road hierarchization is a basic assessment of the use and character of roads in urban areas. The proposed method is based on this principle. By separating the transport-engineering and urbanistic aspect both roles of roads are assessed. The proposed method may be one of the ways to stabilize the links between urbanism and transport infrastructure and offer more specific transport and urbanistic measures. The transport infrastructure is inherently connected to a modal split, as the transport infrastructure affects the modal split and vice versa. This modal split – transport infrastructure feedback is not only defined by a current state but is also significantly influenced by a forward-oriented state. Accurate assessment of roads can lead to a better understanding of individual road functions and roles and to a more accurate design of road structures that are connected to a public space expression. This is also directly related to the concepts of traffic behaviour and sustainable mobility as these concepts are significantly influenced by a modal split, state and hierarchy of the road network and the structure of individual roads. This implies that detailed knowledge of the mentioned functions and roles may lead to specific measures that influence traffic behaviour in a more sustainable manner.

5. Conclusions

In this paper, the authors presented a new method for road hierarchization which is based on methods currently used in the Czech Republic. However, the proposed method is principally different as it is defined by the dualism of roads in urban areas. Both currently used methods, TP 131 and CSN 73 6110, combine transport-engineering and urbanistic aspects into one universal aspect of transport importance. This approach is appropriate to assess roads in nonurban areas but may be too inaccurate if applied in urban areas. This can lead to imprecisely designed transport-engineering measures and/or suppress one of the aspects.

The proposed method strictly separates the transport-engineering and urbanistic aspect and conceptualizes the urban road network according to both aspects. The proposed approach offers more flexibility, accuracy, and detail. On the other hand, it is more time consuming as it requires one to assess a road network twice (from the transport-engineering aspect and from the urbanistic aspect).

Further research is needed to determine whether the proposed approach has its merits or if more adjustments are needed (especially compared to current methods and their effectiveness). However, the authors believe that current methods are not adequate since transport infrastructure and other urban infrastructure are increasingly more intertwined and require stable links to urbanism. For smaller cities, the separation of aspects may be an advantage in development, but for larger cities, the separation may become a necessity for a holistic assessment of a whole road network.

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