Development of «Park-and-Ride» system as a tool for sustainable access control managing

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Abstract. Large cities, whereby people use private transport, are facing the same challenges related to traffic congestion, reliability of public transportation and parking demand. Managing urban traffic and transport has become the most relevant police in transport planning. The article deals with the potential for further implementation in Russian Federation of «Park-and-Ride» recognized as an essential part of the overall transport and parking offer and successful planning tool to reducing congestion for any urban area around the world. The studies have been carried out in Moscow acknowledged as the city core of Moscow agglomeration — the largest and most populous in Russia. The research aims to support for the development of «Park-and-Ride» system applying the methodical approach adapted by the authors for the study to make it relevant for cities. A three-steps access control is offered to reduce private cars use in the city center. The results of the studies shows that such traffic management tool can help successfully in balancing the traffic demand and supply and, consequently, in resolving transport congestion and the number of coherent social, urban and economic challenges addressed to the sustainable development of urban areas.

1. Introduction

Traffic congestion intensifying immensely as the city core becomes closer, is a perennial problem in almost all large and glowing cities across the world. But especially it is argued in the cities which are the centers of agglomeration, conurbation or metropolitan areas where the major traffic streams from external territories to main business and public focus — city center core. Moscow is not an exception because it is the heart of the Moscow agglomeration. It is characterized by everyday dense transport flows to the center of the city from a wide residential area that includes as the midst and peripheral residential areas of the town itself so the suburban and peripheral zones of conglomeration, generating a serious mobility challenge. Estimations of transport planning experts show \([1,2]\) that the overall traffic flow to Moscow center constitutes about 450 thousands vehicles per working day while carrying access capacity of road network is not more than 50 thousands per morning pear hour vehicles per day.

The lack of major community roads capacity to handle excess demand of a population for trips generates sever congestion, which causes many ensuing well known problems such as air pollution caused by motorized traffic, noise, unsafe and uncomfortable travel, difficult accessibility for soft mode trips by foot or by bicycle, time and money waste, etc. Though traffic congestion can be regarded also as the sign of prosperity \([3,4]\), the worth quality of car transport services, various obstacles on the way to the major focus of the working population, bad accessibility for all modes trips to major business, social and cultural city areas adversely have negative effect on the economy of
Moscow agglomeration and, as Moscow is the capital of Russia, definitely do not help to reveal its business potential as well as to preserve and demonstrate its cultural heritage.

Transportation planners and policymakers have long been proponents of different ways and tactics to cope with a still rising mobility challenge in order to provide comfortable and rapid access to the center of the city without waiting in line for a road space. These measures depend on local mobility characteristics, but generally include the decentralization of public and business areas, the reduction of private car use and the development of public transportation system, the construction and reconstruction of new streets and roads, the development and application of traffic and parking management policy and optimization of access control to city centers for different user groups [5,6]. Currently, Moscow agglomeration is characterized by good mobility potential in public transport, which at the moment is one of the main transportation modes of the population.

It is also very popular intermodal transport, that involves using two or more modes of transport in a journey. Usually, people switch from one type of passenger transport to another, but also automobiles, although they are conventionally used as a single-mode form, participate in a various scenarios of combined trips, though not very often (table 1).

Such trends reflect Moscow transport policies aimed at the priority development of intermodal public transport. However, in spite of the measures already taken and tried, the dynamics shows the growth of private motorization: the majority of people as soon as their income permits, prefer to use private automotive vehicles for the simple reason that it still remains more comfortable, flexible and convenient to trip.

| Moscow agglomeration residential area | Population, million people | Working population, million people | Intermodal population mobility to city center in morning peak hours, million people | Car flow to city center, million people |
|----------------------------------------|----------------------------|-----------------------------------|-----------------------------------------------|--------------------------------------|
| Moscow city                            | 12.0                       | 72                                | 2.1                                           | 0.01                                 | 0.3                                  |
| Suburban areas                         | 6.0                        | 3.9                               | 0.75                                          | 0.01                                 | 0.45                                 |

* the data from official web sites of Moscow Transport Department, Transport Ministry, ANO “Moscow transport hub” and authors’ research results

This article examines current studies results for the development and application in Russia of “Park-and-Ride” (“P+R”) system which has been an accepted part of the urban transport across the world as an effective management tool to control the access to city center and to reduce city road congestion and parking problems. The experience of Moscow agglomeration — the biggest one in Russia — is held up as a model which other cities can seek to emulate.

“Park-and-Ride” facilities have been already arranged on the available spaces near to Moscow subway stations. The analysis of its operation, popularity and contribution to urban traffic have encouraged the authors to investigate the potential for «Park-and-Ride» schemes and make an assumption that further successful management of overall urban transport problems in Moscow agglomeration demands developing «Park-and-Ride» system integrated in overall transport net.

The authors hypothesis is that a «Park-and-Ride» system will improve the utilization of the existing facilities also by enhancing the synergetic effect of the operation of each of the parking lots, resulting such arching objectives as provision an alternative to car use, provision of efficient parking capacity, reducing car use, congestion and air pollution in the city centre and managing problems related to changing patterns of population mobility.
2. Literature review

«Park-and-Ride» facility, being a specific transit element of the urban transport network, suggests a wide range of studies, experienced in this research. All the studies agree that the challenge of managing traffic in growing cities and agglomerations is still increasing while space to develop road network in limited or even absent. To select efficient and successful traffic management services and solutions both to meet local conditions of mobility characteristics and balanced between throughput, livability, safety and sustainability, has become nowadays the most important issue of urban transport policy across the world, including Russia. The authors of the articles have been conducting research in the field of intermodal transport service system and public transport transit hubs development for more than 7 years. During this time, the authors have accumulated extensive experience in the transport planning on intermodal public mobility [7-9] and, in parallel, good knowledge of both domestic [10,11] and international experience in studying the problems of access control to the road network [12,13].

Forecasting the mobility of the population through the "P+R" system builds upon a sociological study [14] that reflects the objective pattern of transport behavior of the population in Russian cities. Also, it was examined current experience in sustainable development of urbanized territories to define general goals and strategy of "P+R" system in the context of urban development demand [15,16]. A comprehensive analysis on current traffic and urban planning and design, and experience in managing access control to city road network make it possible to form a comprehensive view of «P+R» system as an essential integral part of the overall transport system for any urban area in Russia, providing solutions on the problems related to urban mobility.

3. Materials and methods

The approach presented to develop «Park-and-Ride» system builds upon a classic four step model applied to study transport systems. The process allows to solve problems using methods of systematic analysis. It is focused on the area of Moscow and Moscow region that form Moscow agglomeration — the largest one in Russia. Zoning of the territory of Moscow agglomeration allows to define the zones having characteristic access conditions to the urban core (Figure 1).

City core area encircled by The Moscow Automobile Ring Road, normative access to city center about 40 min;
- Suburban area bordered by the Small Ring Road, normative access to city center about 1 hour 20 min;
- Peripheral suburban zone bordered mainly by the Big Ring Road and limited by the average time per day spent in home-to-work travel and, accordingly, access to city center about 2 hours.

![Figure1. Moscow agglomeration territory zoning](image-url)
Today, morning peak-hour private vehicle home-to-work trips do not meet the regulatory time requirements. The way to cope with this problem is to expand public transit capacity by developing transport transit hubs intermodal trips to shift people from private cars to rapid modes of public transit. Currently, quality public interchange points providing comfortable conditions for public transit are already in process of planning and construction. The question consists in choosing the right potential transport hub to locate successful intermodal infrastructure and in determining its capacity. Analysis of the transport behavior of the population [] shows that when the government implements preferential tariffs or payment methods for travel, it is travel time that becomes the decisive factor. Based on this, the users category of «P+R» should be the car owners, spending less time for intermodal trip than for one-mode private trip (Figure 2).

![Figure 2. Scenarios of motorists nobility to city center](image)

Structured approach to «Park-and-Ride» system allows efficient way to intercept private motorists. The model of transport demand and supply provides for precise guideline in study of intermodal transportation to help development for such infrastructure system as «Park-and-Ride». The need of expediency selection of the most rational and optimal scheme ensuring a balance between transport demand and supply for every system facility, determines the necessity to examine this issue applying methods of systematic comprehensive analysis. This approach works from an integrated viewpoint for the city’s transport system in line with the policy for sustainable urban mobility planning and includes the following steps:

1. Planning and transport analysis of the current state of the city intermodal transport hubs aimed at selection of potential location of «Park-and-Ride» objects.
2. Planning and transport analysis of every potential location of «Park-and-Ride» object aimed at defining basic classification criteria.
3. Classification of «Park-and-Ride» system objects.
4. Determination of composition and structure of «Park-and-Ride» system and horizontal and vertical linkages inside the system.

At the first step of a comprehensive analysis, the factors listed below are the main to be taken in consideration while choosing preliminary decision about potential location of «P+R»:

- good centripetal public transport coverage across the area concerned, ensuring labor trips of the population towards social gravity focuses of social with minimum time costs;
- accessibility of motorized transport to transit hub;
- sufficient territory resources in the transit hub for effective placing and operation of «P+R» facilities;
- relatively dense housing close to hub;
- mass public home-to-work travels towards the city center.

The authors analysis of the above listed factors in Moscow agglomeration settlement allowed:

1. To select the passenger transit systems that meets the conditions of the applied methodology, such as:
   - Moscow Subway,
   - Moscow Central Circle,
• Moscow Region commuter suburban railways.

2. To define the boundaries of the «Park-and-Ride» system facilities basing on the normative accessibility to the Moscow city center making intermodal trips by means of one of the selected public transit systems.

3. To select all intermodal transportation hubs from those existing on the selected passenger transport systems, corresponding to the following criteria:
   • the station operates passenger traffic;
   • the station is located within residential area with a dense permanent resident population;
   • the time of the centripetal home-to-work trip on passenger mode of transport is less or equal to the time of the same trip made by private car.

In the result, the total number of intermodal transportation hubs suiting the requirements for potential location of «Park-and-Ride» system facilities is as follows:
   - 143 stations of the Moscow Subway located in high density residential areas on the peripheral and partly middle zones of the Moscow city within the limits of the Moscow Central Circle;
   - 31 stations on Moscow Central Circus;
   - 259 stations on the commuter railways in suburban areas of Moscow agglomeration.

The second stage of analysis is aimed at determining the initial parameters for classification of «P+R» system objects. The algorithm of classification is based on the analysis of transport supply and demand factors that provide possibility to use «P+R» as a tool for managing access control to the city center. At this step the authors have analyses the following factors:
   • time costs and operating conditions of passenger transport ensuring daily home-to-work trips directed to the city center;
   • operating conditions of street and road network, providing access to public transport for residents of the transport transit hub gravity zone;
   • current state of the urban and transport hub infrastructure development: more services — more users.

The areas of potential influence of every future «P+R» object were defined as a proper one for gathering of analytical information. These are the areas of predominant generation of intermodal trips users «private car — passenger transport», who tend to specific transport transit hub with «P+R» facility incorporated. Consequently, it is characterizes by the highest demand for «P+R» services and at the same time, by the highest concentration of public services infrastructure. Defining limits and parameters of the “P+R” influenced zone is necessary both for the stages of mathematical model development and experimental practicing.

The research hypothesis suggests that the size of the influenced zone is a major determinant of the system structure and parameters. That’s why the classification of «P+R» facilities into Groups should be done on the basis of the size criteria. Possibility to arrange objects in distinguishing groups according to homogeneous criteria — that is classification — is one of the most important indicators of the system. In Moscow agglomeration, the sampled objects for classification were intermodal transportation hubs corresponding to such requirements for «Park-and-Ride» location as:
   • meeting of population demand for “P+R” service;
   • providing urban and transport infrastructures.

The development of «P+R» system on the basis of selected transport hubs as an integral part of planning and transport strategy will make it possible to use the hubs potential to maximize use of sustainable travel options and reduce city center congestion.

The expediency of «P+R» objects classification is caused by the necessity of knowledge arrangement by defining the main characteristic criteria and parameters that describe each elementary group of facilities, that is of a special importance as for the development of scientific approach so for practical activities.

The essential criteria for classification of the system are the following:
1. Size of «P+R» influenced zone and
2. General integral indicator $I_{P+R}$ allowing to unite different characteristics of a «P+R» influenced zone.

These criteria will reflect:
- the level of population demand for intermodal trips using a specific «P+R» facility;
- the role and main characteristics of a «P+R» facility in overall urban transportation;
- structure of a «P+R» system.

The size of the zone of «P+R» influence should be determined considering two factors. The first aspect is a circle radius with the center in the hub — empirical parameter obtained on the basis of data on the settlement patterns and statistically significant in residential areas. It is a fixed distance from a transport hub with minimum penetration of 2200 m. Such radius defines a zone of transport accessibility where the share of private vehicle uses increases as you move away from the hub. The second aspect is that this radius is the shortest-path distance between two points and the real distance can be much longer, always depending on such factors as specific pattern of settlement, traffic speed and intensity on the arterial roads.

The multi-level task determines the need for the introduction of integrated indicators for assessing each of the factors determining the capacity of the transit hub to suite «Park-and-Ride» facilities. For unified analysis of experimental data, it was adopted indicators system to rate the influence of each factors on intermodal trip demand from 0 up to 4, as it is represented in the Table 2.

Value of integral indicator $I_{P+R}$ is described by the formula:

$$I_{P+R} = I_1 * I_2 * I_3 * I_4,$$

where $I_1, I_2, I_3, I_4$ - integral indexes for evaluating of every factor.

### Table 2. The system of unified integral indicators for evaluating of the transport demand on “P+R” service in public transport transit hub

| Factor                        | Indicator                                                                 | Evaluating scale |
|-------------------------------|---------------------------------------------------------------------------|------------------|
| Public transport availability | $I_1$ intensity of traffic flow*                                            | 0                |
|                               |                                                                           | 1                |
|                               |                                                                           | 2                |
|                               |                                                                           | 3                |
|                               | Frequency of traffic vehicles per morning peak hours                       | 0-3              |
|                               |                                                                           | 4-10             |
|                               |                                                                           | More than 10     |
|                               |                                                                           | -                |
|                               | $I_2$ access to city center**                                              | -                |
|                               |                                                                           | Limited access   |
| Road network availability     | $I_3$ road / street classification                                         | -                |
|                               |                                                                           | Local street     |
|                               |                                                                           | Collector street |
|                               |                                                                           | Arterial road straight to city center|
| Transport transit hub availability | $I_4$ level of development                                                 | No development   |
|                               |                                                                           | Low level        |
|                               |                                                                           | High level       |
|                               |                                                                           | -                |

* Morning peak hour - 2 hours: or from 6.00 to 7.00 AM or 7.00 to 8.00 AM.

** Limited access implies the need to change the type of high-speed passenger transport.

General set of “P+R” sites was formed from the object with non-zero $I_{P+R}$ value, i.e satisfying to the condition:

$$I_{P+R} = \begin{cases} I_1 = (1,2) \\ I_2 = (1,2) \\ I_3 = (1,2,3) \\ I_4 = (1,2) \end{cases} \neq \{1,2,4,8,12,16,24\}$$

(2)
The total number of elements for the study consisted of 181 transport hubs, including both commuter railway stations in suburbs and subway stations in Moscow city, so forming unique system with potential capacity to accommodate «P+R» facilities.

The concept for «P+R» system developing consists in three-step intercept of the traffic along its way to the city center (figure 3).

![Figure 3](image)

**Figure 3.** Mechanism of providing access to city center by a “P+R” system

Each step is represented by a classic system element of a certain size, playing a specific role in managing access to the city core. Thus, the «P+R» facilities can be classified in the following Groups:

- Group 1 — «P+R» facilities of **regional importance** having maximum size of influence area in metropolis and maximum integral indicator (that is typical for existing transport hubs with a high intensity of passenger traffic);
- Group 2 — «P+R» facilities of **urban importance** having influence area in the size of a limited residential one, concentrated along the collector streets and roads providing direct access to transport hub. The total integrated index of such facilities may vary widely, depending on the population and the intensity of passenger traffic at the station;
- Group 3 — «P+R» facilities of **local importance**, where the influence area lies in the boundaries of a town or town district, gravitating to a certain transport hub.

In this case, the main goal of classification development will be to determine the boundaries of the classification Groups according to specific criteria.

To split the aggregate data into homogeneous groups, the authors have used the k-means clustering method. The algorithm splits all sampling objects into k sections (k < n), which are clusters. The results of clustering consisting of 181 elements and calculations of each iteration are presented in table 3.

| Iteration | Cluster centroid | Quantity of element in cluster | Mean square error |
|-----------|------------------|--------------------------------|------------------|
|           | 1 | 2 | 3 | 1 | 2 | 3 |                |
| 1         | (1;200) | (1;60) | (1;10) | 15 | 17 | 149 | 112720          |
| 2         | (20.8;218.00) | (13.41;6.24) | (8.85;9.52) | 14 | 17 | 150 | 87989.5127      |
| 3         | (21.71;223.93) | (13.65;69.06) | (8.82;9.7) | 14 | 17 | 150 | 86896.2497      |
| 4         | (21.71;223.93) | (13.65;69.06) | (8.82;9.7) | 14 | 17 | 150 | 86896.2497      |

$\Delta = 0$
Calculated boundaries of classification groups are shown on the diagram (figure 4).

4. Results
Coordination of the «P+R» system is carried out by implementing mechanism for access management to the central city core. The managed target group consists of car owners moving from residential areas to the working places concentrated in city center direction. So, to obtain long-term results through performing the basic «P+R» system function of access road control, it should be necessary to reach the main goal, that is to make «P+R» services attractive to the maximum number of potential users. Proposed classification allows hierarchical access control for this target group at any part of the trip. Graphically, it is presented on figure 5.

5. Discussion
In view of the actual character of the studies concerning the development of «P+R» facilities being in corse in Moscow agglomeration, the authors believe the results obtained—consisting in systematic approach to building of «P+R» lots justified by local characteristics of urban settlements and public transport behavior—would find both scientific and practical value.

The proposed structure for Moscow agglomeration «P+R» system is fully in line with transport sustainable development policy trends in the largest Russian citied, aimed at priority development of public transport in managing congestion. The implementation of «P+R» system will undoubtedly provide for access control to the city center by intercepting of a significant part of car flow, especially that of private vehicles. When it is necessary to limit a centripetal highway system traffic, «P+R» system offers to private vehicle drivers the alternative mode of travel, emphasizing effectiveness of transport system operation in agglomeration.

- the main advantages of the proposed functional organizational of "Park and Ride" system structure are as follows:
  - definite intersystem arrangement for system management;
  - the efficiency and rationality of the system construction, possibility to reduce or increase the number of elements to suit for a specific investment plan without loss of functional integrity;

![Figure 4. Boundary diagramm of “P+R” classification groups](image)

![Figure 5. Structure of “Park-and-Ride” system](image)
• the system's adaptability when there is feedback control of the managed object: the justified decision-making on the development of the transport infrastructure in case of changes in external conditions (such as the development of transport infrastructure, development of territories) providing for additional transport flows.

6. Conclusions
Thus, it is acknowledged that the main function of «P+R» system consists in access control to the city center by intercepting centripetal car flows. To make this function successful, the «P+R» system should have a hierarchical organization where vertical links provides for tree-level access control, while horizontal links provide for:

1. optimal operation of each «P+R» facility of the same Group, provided by presence of homogeneous elements parameters;
2. coherence of the system having set up the relationships and boundaries between the Groups;
3. synergetic effect of the system's operation consisting in strengthening of urban planning and transport effect in cooperation and coordination of system elements.

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