

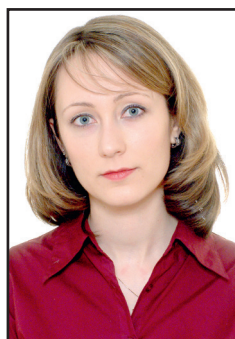
On the Principles of Design of Transport Nodes



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ABSTRACT

The methodology developed by the authors refers to designing, calculating, and optimising transport nodes based on the original systemic approach as a main method. The use of the methodology will make it possible to design transport nodes more rationally and to evaluate their development projects more correctly.

A «system» is understood as a general natural form of structuring organised substance, which enables it to function stably in a changeable environment. The basic principles are formulated as follows: the system consists of elements, each of which is also a system; active self-maintenance is developed in the system, that is, active actions are counteracting external adverse influences; it is shown that self-maintenance is provided by adaptability, and in transport systems the self-maintenance is particularly provided by adaptive technology.

A contradiction (a dialectical one) arises: on the one hand, the elements are independent systems that have their own system parameters and mechanisms for their active maintenance, and on the other hand, they are subordinate creatures capable of flexibly changing their work to maintain the parameters of the supersystem. It is necessary to find harmony between the levels of development of these opposite properties. Transport nodes are also considered from these systemic positions. Exposition of several definitions of nodes by leading national scientists is followed by a statement showing that they all contradict the new systemic approach.

Suggested system definition of a node describes it as a set of stations. The authors also propose a new classification of transport nodes, formulate criteria for their rational design depending on the classes, and propose correct design and optimisation principles.

Keywords: transport node, system, simulation model, station, adaptability, technology, design, optimisation.

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INTRODUCTION

The article presents the results of solving the task of developing theoretical foundations for designing effective transport nodes¹, as well as correct methods to be used for their design and optimisation. The theoretical basis refers to the original version of the *systemic approach*, where the «system» is understood as a natural form of structuring organised substance, which provides it with stable and effective functioning in a random environment.

RESULTS

Systemic Approach and Transport Nodes

A correct understanding of the essence of transport nodes and methods of their design is of great importance in the context of development of transport infrastructure.

Design principles mean design method, and choosing a method is not an easy task.

According to Georg Wilhelm Friedrich Hegel, «Method, therefore, is not an external activity of subjective thought, but the very soul of the content» [1, p. 423].

Alexander I. Herzen has no less authoritative point of view: «The method in science is more important than any amount of knowledge». «The method follows from the object and is not introduced to it arbitrarily» [2, p. 134, 155].

Thus, to choose fundamentally new approaches to calculating transport nodes, one must answer the question: what is a transport

node? Definitions there-of are suggested in several research works in the field of transport science.

Academician Vladimir N. Obratsov wrote: «A railway node is a point where at least three railway lines (three directions) of a relatively equivalent mainline nature are connected to each other, and where there is one or several distribution stations, which serve to exchange of traffic of passenger and cargo trains and wagons, as well as for passenger transfer and transshipment of goods to other modes of transport: waterways, highways, narrow-gauge railroads, etc.» [3, p. 7].

A node is called here a «point» which contains intersecting lines and at least one station. How can a single station be a node? This follows from the presence of intersecting lines (Pic. 1). This is the definition of a geometric character. The term «point» later became popular.

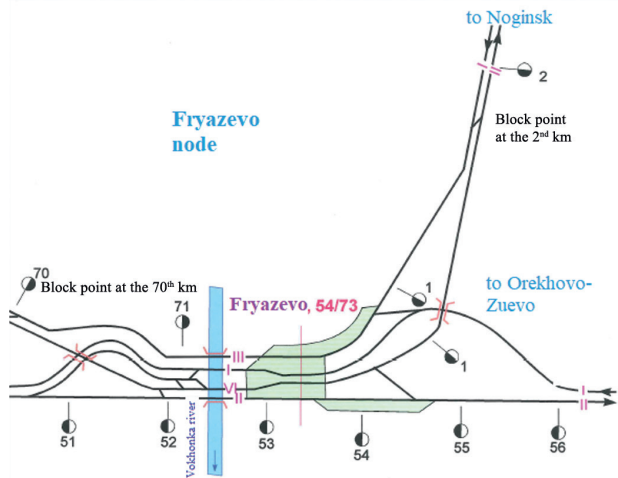
V. N. Obratsov gave the following definition of a transport node: «A transport node is a point of intersection and branching of routes of various modes of transport» [4, p. 433].

Professor Prokopy V. Bartenev believed that «...a transport node is a point of concentration of various modes of transport» [5, p. 452].

Professor Vladimir A. Persianov noted that, although the above definitions are basically correct, they are insufficient, since they do not fully reflect the entire essence of the transport node, and that the classification of transport nodes contains more random than consistent features [6, p. 355].

The Institute of Systemic Transport Problems (then affiliated structure of the Academy of Sciences) proposed a more meaningful definition: «A transport node is a complex of transport

¹ The authors in the context of the research use the original Russian term «transport node» as the most general one, without further differentiation into, e.g., nodes, hubs, multimodal interchange nodes, multimodal interchange hubs, etc. – Translator’s note.



Pic. 1. «Node» consisting of a single station (compiled from the album of plans and layouts of railway nodes and stations, developed by JSC IERT [Institute for Transport Economics and Development]).



structures and [track] developments at the point of junction of several modes of transport (including at least two modes of mainline transport) that jointly operate transit, local and urban transportation of goods and passengers» [7, p. 181].

But again, the «junction», and the structures can hardly be considered something definite.

The recently published work on the nodes states the following: «A railway node is a point of intersection or branching of several lines that unite a number of stations and block points linked by connecting lines and working according to a single technology (in interaction). The railway node includes marshalling yards, cargo and passenger stations with their structures; main and connecting tracks; block points and bypasses; feeder roads; all types of flying junctions located within the boundaries of the node; independent production units of railway transport (factories, traction substations, material warehouses, etc.)» [8, p. 787].

Here, the notorious «point» includes not only «stations and factories», but also «connecting tracks, block points, and bypasses, and all types of flying junctions».

If a transport node is a «junction» that includes different «structures», then it is difficult to determine the content of this conceptual term, and, therefore, it is difficult to choose an adequate design method.

Several decades ago, scientists representing various fields widely discussed the so-called «systemic approach». The term «system» and its variations are often used in different phrases and context: «to consider from a systemic standpoint, problems are of a systemic nature», etc. There is even an institute for systems analysis². Maybe it is worth considering the transport node from a systemic point of view as well?

Let's see what is understood in science by the notion of a «system».

Based on the works of Friedrich Engels [9, pp. 392, 550, 563, 570, 585], the philosopher Anatoly N. Averyanov suggested a definition that follows: «The system is a limited set of interacting elements» [10, pp. 18, 24].

The mathematician Nikita N. Moiseev believed that «the concept of a «system» is one of those for which it is difficult to give an accurate definition. For our purposes, the intuitive concept

of a system, that everyone studying a subject has, is sufficient» [11, p. 130].

But a whole field of science, the systems theory, cannot be built on an intuitive concept.

There are also such approaches that attribute too broad classes of objects to systems. Here is what, for example, Anatoly N. Averyanov writes in the above cited work: «...unorganised aggregates... are systems, although not integral ones...», further noting that «...unorganised aggregates consist of elements; the elements of specific aggregates are interconnected, no matter if this connection is external or accidental; ...it is important that this connection unites the elements into aggregates of a certain form, which we call a heap, a pile, a crowd, etc., depending on the properties of its elements and the links between the elements that differentiate those aggregates from external environment» [10, pp. 21–22].

But if one and the same concept includes, e.g., a transport node and a heap of stones, then what content can a theory based on this concept have?

It is widely believed that there is no generally accepted definition of the concept of a «system». Naturally, there is no certainty as to what problems the theory should solve.

Academician Axel I. Berg expressed the following opinion: «Despite the widespread use of the notion of the «system», until now there is no generally accepted definition of it» [12, p. 68].

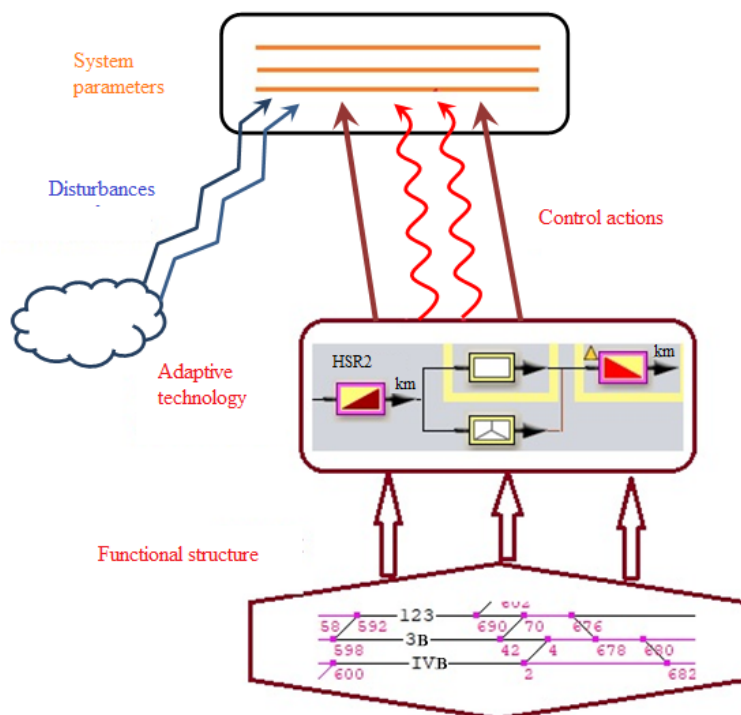
To some extent, currently, there are attempts to touch upon this problem but without going beyond the usual definition of the concept of a «system». For example, in [13] the authors write: «The system is such a general concept that it is very difficult to provide it with a definition that could be universal for all cases of life. Systems are simple, complex, and super-complex, etc. An ordinary sash fastener is a simple system. Personal computer is a complex system. The economics of passenger transportation is a super-complex system».

When both «sash fastener» and «economics of passenger transportation» are deemed to be equivalent concepts, this approach can hardly be a theoretical basis.

As we can see, not all is correct with the systemic approach.

A new approach to this problem was proposed in works [14; 15]: «a system is an integral holistic formation with active self-maintenance, while its elements are also systems». Here «active self-

² Institute for Systems Analysis of the Russian Academy of Sciences. – Translator's note.



Pic. 2. The main features of the systemic design of an object (developed by the authors).

maintenance» is just as important as «integrity». Avicenna said that life is given to a person with an indispensable condition to fight for it every day [16, p. 272]. For artificially created systems, this is the main difference from all other objects (there is integrity in a meat grinder, a bicycle, but there is no active self-maintenance).

That is, a *system* is a form of structuring organised substance that allows it to stably (and efficiently, that is, without large static spare resources, but due to adaptability) exist in an environment where there is a disorganisation. This form has been developed by nature. This form must be studied, stated clearly and then used to design sustainable and efficient transport systems.

Active self-preservation ensures adaptability. For technical systems, this will be an adaptive technology.

The essence of systems analysis follows from the concept of a system. It should use the following steps:

- To determine the general function and parameters that characterise it.
- To formulate the function and system parameters of the elements.
- To investigate the adverse effects on the system as a whole and on the elements as a system.

- To determine the mechanisms of active counteraction to these disruptive influences.

Definitions

Transport node is a group of systems of various modes of transport interrelated by infrastructure and technology that jointly process flows in a certain area.

Railway node is a group of stations interrelated by infrastructure and technology that jointly process flows in a certain area.

District is a certain isolated integrity in the social (settlement), industrial (plant) or transport relation. In the latter, it is the fulfilment of a certain transport task according to a single plan: provision of coordinated transport services to heterogeneous objects in the area, processing the flow when transferring it from one line to another, etc.

Processing of flows:

- Disassembly and assembly of trains.
- Loading, unloading, reloading.
- Embarkation, disembarkation, transfer of passengers.

The signs of the term «jointly» are evident if operational control is additionally present, that is, there is a flexible interaction of the systems included in the node (this is a higher level).

A node is a system only when there is a common function for the whole node, and if



there are parameters that characterise the function and mechanisms of their active maintenance in the presence of disturbing factors (Pic. 2). Otherwise, it is not a system.

We might single out also the following foreign works as examples of studies dedicated to the analysis and design of transport nodes, railway stations, areas [17–21].

So, here are the features of the system:

- *There is a common function and parameters* that characterise it, while there are permissible limits of the parameters.

- *There are destructive influences* that can bring the parameters beyond the permissible limits.

- *Regarding each set of destructive effects, there are active reactions* that neutralise harmful effects.

- Active reactions are provided mainly due to *adaptive technology*.

- *The structure* should be largely determined by the function, that is, the structure should be *functional*.

Differences from the existing definition:

- Here *a node is a system of a higher organisational level*, the elements of which are systems of the lower level, and not connecting lines, tracks, sidings, junctions, berths, etc.

- The main thing here is *the nature of interaction* of the systems included in the node, and *not its geometric characteristics*, which directly depend on the terrain and location of the object served by the transport.

From this point of view, transport nodes are clearly divided into two classes:

- *A class: nodes are systems.*
- *B class: nodes are not systems.*

This means that a systemic approach should be used in the study of the former (*A class*) nodes, while some other technology should be applied to the latter (*B class*) nodes.

The analysis shows that only industrial and port transport nodes can be classified as belonging to *A class*.

There, the structure is really what is called a «frozen function». These nodes have functional integrity, have a system-wide function and mechanisms to maintain it. They are strongly affected by the proximity to production loading facilities.

Transit nodes (*B class*) cannot be considered fully fledged systems. What is the general function of a node that includes, say, a passenger and cargo stations along with

a marshalling yard? Each station has its own individual function and there is no adaptive interaction between them. They, as a rule, are located near a large settlement: otherwise, they will not be able to hire the necessary number of employees.

But here comes another problem of interaction between stations. There is an intersection of flows and with it the need arises to build expensive interchanges and flying junctions at different levels.

Here, rather, there is a problem of designing a node with minimal and functional losses considering specific geographic conditions. These conditions precondition emergence of various node layouts. Nevertheless, some principles of their rational organisation can be formulated:

a) Stations should be located as close as possible to the facilities served:

$$\forall_i \forall_j |l_{ij}| \rightarrow \min,$$

where l_{ij} is distance of the i -th station from the j -th terminal.

b) The location of the infrastructure of stations should ensure:

– minimum of intersecting flows:

$$\sum_i \sum_j u_{ij} = \min,$$

where i is the origin point of the intra-node flow; j is intersection point.

c) Minimum of intra-node mileage:

$$\sum_i \sum_j u_{ij} l_{ij} = \min,$$

where u_{ij} is transportation flow between the i -th and j -th station of the node;

l_{ij} is length of u_{ij} trains mileage.

Then, constraints of topographic nature and creativity of designers take effect.

To calculate transport nodes of both classes, a two-stage approach should be used.

The objectives of the first stage will be:

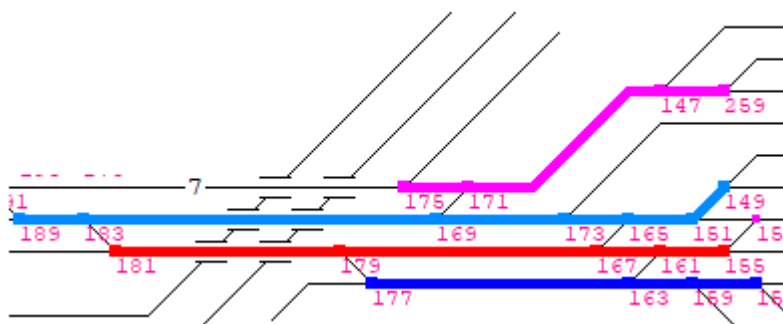
- Determination of the general parameters of a node.

- Assessment of inter-station interaction, that is, structural and functional links between stations.

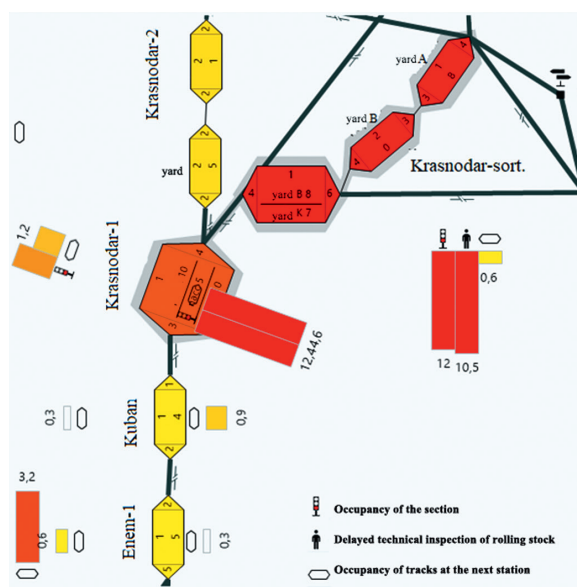
- Identification of stations that experience problems.

At the second stage, the task will be to thoroughly and comprehensively study stations experiencing problems.

A two-step approach will reduce study costs and speed up the entire process.



Pic. 3. Structural channels in the neck (developed by the authors).



Pic. 4. Possible reasons for train delays at the stations of the node (developed by the authors).

At the first stage, it is advisable to apply integrated modelling, and at the second, to use detailed simulation models.

- An integrated study can be carried out using:
- Optimisation flow models.
- Integrated simulation models.

In the general case, three problems can be solved using flow models:

- To make a rough estimate of the transit and processing capacity of stations.
- To assess the transit capacity and delays in inter-station structural links.
- To optimise the process of adaptive interaction of stations (for *A* class nodes).

It is more useful to use dynamic models, for example, a dynamic transport problem [22]. Even for *B* class nodes, this is important since the delays due to intersection of flows

will be presented in dynamics. This is important for analysis since flows are generally uneven.

The development of an enlarged simulation model requires development of a special technology [23]. Instead of switches, at the necks, so-called structural channels are introduced, reflecting the number of possible parallel movements (Pic. 3).

In the yard, instead of the total track capacity, its functional capacity is specified, that is, the maximum filling, at which its functional properties are still preserved. The reliability of macro-modelling was verified by comparative calculations regarding, respectively, detailed, and integrated models [23].

In Russia, the IMETRA simulation software package [Certificate of state registration of



computer programs No. 2015662972] can now be considered as most effective. The package provides comprehensive information about the parameters of the node, as a rule, in a form convenient for the researcher (Pic. 4).

CONCLUSION

Classification of transport nodes from the standpoint of a new systemic approach better reflects their nature.

A two-stage approach should be used to calculate transport nodes. The first stage should be dedicated to investigating of inter-station interaction with the help of integrated models, the second stage based on the detailed models should be dedicated to the study of the stations experiencing problems.

The classification of transport nodes allows for a more reasonable development of methods for their design and optimisation. Using them while assessing infrastructure development projects will result in a significant effect.

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