Evolutionary and functional development of transport nodes

O Pokrovskaya\textsuperscript{1,4}, P Kurenkov\textsuperscript{2,5}, I Khmelev\textsuperscript{3,6} and S Goncharenko\textsuperscript{2,7}

\textsuperscript{1}Emperor Alexander I St. Petersburg State Transport University (PGUPS), Moskovsky pr., building 9, 190031, St. Petersburg, Russian Federation
\textsuperscript{2}Russian University of Transport. RUT – MIIT Obraztsova, 9, building 9, 127994, Moscow, Russian Federation
\textsuperscript{3}Plekhanov Russian University of Economics, Stremyanny lane, 36, Moscow, 117997, Russian Federation

E-mail: 4insight1986@inbox.ru, 5petrkurenkov@mail.ru, 6KHmelev.IB@rea.ru, 7goncharenkoss@mail.ru

Abstract. The relevance of the research topic is determined by the fact that the effectiveness of the logistics complex of the whole country depends on the quality of decisions on the creation of terminal systems in the regions. The state and development of industry, agriculture, defense of the country and, in many respects, well-being and convenience for the population depend on the quality of the functioning of the transport system. Integrated directions, the tasks of which would be a multifactorial study of such complex logistic entities as terminal networks are still not sufficiently studied in modern transport science. The scientific article proposes an evolutionary-functional approach to the classification of transport nodes, which can be used as a technique for studying the features of the origin and development of transport nodes. The pyramid of terminalistics and the hierarchy of its objects is present taking into account the complexity and integration of the service as an adapted version, according to the theory of J.-P. Rodrigue. For railway junctions, a four-stage adapted Rodrigue-Notteboom model is proposed. The stages of the development of the transport hub according to the evolutionary-functional approach are investigated. A model for the development of logistics facilities is proposed (for example, Venlo Trade Port). It is summarized that the development of transport hubs can be effective for industries not related to transport and warehouse logistics, but for such industries, the development of transport hubs will have social and financial effects.

1. Introduction
In modern conditions, transport hubs have long been playing the role of full-fledged multifunctional logistics facilities that implement a wide range of not only transport, storage, but also consulting, customs, distribution, expeditionary and other services. In this regard, the main goal of activities in this area is the creation of an effective logistics system on the network of Russian railways, the elements of which will be integrated into Russian and international transport systems; ensuring the entry of domestic enterprises into new high-tech and highly profitable markets for logistics services. It should be noted that the Government of the Russian Federation in the Strategy for the Development of Railway Transport in the Russian Federation until 2030 provides for the construction of terminal and logistics centers in the largest transport hubs of the country. The tasks of the effective development of the logistics market are crucial for the entire transport system of Russia, since they take into account the lower level of equipment of the transport and logistics infrastructure in Russia, as well as the level
of quality and comprehensiveness of transport services (compared with leading European countries) [1].

Issues of nucleation, formation and evolution are fundamental in the design of technical equipment, work technology, organization mechanism and inter-element interaction of such complex systems as transport nodes. The role of transport hubs in the delivery of goods is difficult to overestimate. The effectiveness of the country's transport and logistics system depends on their work.

2. Study methodology

In foreign and domestic scientific literature, there are publications devoted to individual issues of creating terminal systems. So, the work of such scientists as: Gasparik J., Malikov O., Pokrovskaya O., Kurenkov P., internal technological design of cargo terminals and warehouses - Majercak, J., Mesko P., are devoted to the organization and calculation of transport and freight systems, Mirotin L., Panak M.

The study used the following methods: systematic approach, comparative analysis, modeling method, analysis of official statistics; document analysis method.

The aim of the article is to develop theoretical aspects of the development of transport nodes from the perspective of terminalistics - logistics of transport nodes and terminal networks, as a new scientific direction. In particular, consideration of the evolutionary-functional approach to the development of transport nodes as multimodal logistics facilities. At the same time, it is believe that the transport hubs have a railway logistics facility.

The hypothesis of the study is that with the widespread occurrence of terminal transportation, a huge and constantly growing number of logistics centers (from warehouses with a minimum of functions to logistics centers of full-cycle providers), there is no comprehensive scientific approach that focuses on a comprehensive study of logistics centers - from classification typologies and issues of spatial-quantitative formation of terminal networks before designing and operating logistics centers in chains yah supplies.

3. Assessment and results

Terminalistics - logistics of terminal networks and transport nodes - the science of the organization, design, management, structure and configuration of freight terminal networks, including the number and location of nodes, functional and technological composition, forecast and expert assessment, as well as transport, infrastructure, integration, economic and environmental components of the work of regional terminal networks [2].

Logistic object - a key element of the transport and storage infrastructure system that performs a set of logistic functions in the system of cargo delivery from the initial supplier to the final consumer. In the general case, it is assume that the logistics facility is at the heart of the infrastructure of any transport and storage system facility.

Logistic region - a set of logistics facilities of a certain degree of economic and technological interaction, concentrated on a number of signs in spatial and geographical concentration.

The logistics area is a set of interconnected logistics areas that provides integration into transport corridors and the construction of a terminal network that is stable in composition and complexity of the transport and logistics service [3].

In figure 1 the pyramid of terminalistics and the hierarchy of its objects given - classification, taking into account the complexity and integration of the service provided by these objects.

In addition, in terms of export-import operations, multimodal transport hubs should have exits outside the state and be a center for the processing and transportation of international, including transit, goods. At the same time, they will be the nodal points that allow collecting information, tracking and controlling the passage of international transit goods, including containers, providing a full range of services for these goods [4,5].

The development of any transport hub as a logistics facility, taking into account spatial and power evolution, the complexity of the logistics functionality, can be represented by the following stages:
1. “node” on which, with the development of intra-node interaction, conditions are formed for the provision of additional service and transition to a new stage;
2. “docking point” of the means of transport, at which the interaction becomes inter-nodal, and the service allows supporting complex cargo delivery systems;
3. “multimodal transport and logistics center”, which provides a comprehensive end-to-end service for clientele, rolling stock, cargo (“seamless technology”). This is shown in Fig. 2 [6].

**Figure 1.** Adapted pyramid of terminalistics and its objects.

**Figure 2.** The enlarged evolution of the transport hub.

In particular, it is propose to adapt the Rodrigue-Notteboom model [7,8] for railway transport hubs taking into account the theoretical foundations of terminalistics, which is reflect in Figure 3.

Given the transformation of internal logistics processes, the development of a node (network of nodes) occurs in four stages:

1. the fragmented existence of individual elements (objects);
2. concentration (consolidation, concentration and integration of elements (objects) into a node (nodal infrastructure element);
3. building up infrastructure (connecting auxiliary elements, building up expanded infrastructure support);
4. regionalization with subsequent exit to a new level (“connection” to local and global logistics systems) (according to concepts [9-12]).

The evolutionary-functional approach reflects the development of transport hubs in the direction of logistics services and integrates the gradation of the logistics service and orientation to the service object.

Three stages distinguished according to the gradation of the level of services: standard service = >> extended service = >> unique service. In addition to improving the level of service, there is a gradual shift in the key orientation of the service: internal environment = >> external environment = >> client.

A distinctive feature of the proposed classification of transport nodes is the synthesis of cluster and synergetic approaches to determining the stage of development of transport nodes as a logistic object.
on the one hand, and a self-organizing complex system, on the other hand. The basis is a sign of the perfection of logistic decisions in the interaction of the parties to the logistics (taking into account Figure 1), as well as the theory of warehouse systems Malikov [13], transport and logistics clusters and hinterlands.

**Figure 3.** Adaptation of the Rodrigue-Notteboom model to railway transport nodes [7].

Let us consider in more detail the proposed evolutionary-functional approach by stages. We consider in more detail the proposed evolutionary-functional approach by stages.

The stage of development (evolution) of any transport hub is a period of time during which it moves to a different qualitative level in the process of changing its role in the logistics system of cargo delivery, taking into account the range, orientation and complexity of the logistics functions performed in interaction with the external environment of the transport and logistics market. A number of parameters achieved at a given time characterizes each stage. These parameters determine its type and place in the hierarchy of terminal objects, taking into account the features of functional, spatial, technological, technical and organizational development. Figure 4 shows the proposed allocation of the stages of the evolutionary and functional development of the transport node.

The stage of "nucleation" corresponds to the stage of chaos (chaotic development) of the node. As noted in the central block, the infrastructure base is the existing base, the corresponding development of which can take place in the form of reconstruction or new construction. Conditions are being create for the formation of a center of attraction of labor, financial and other resources. However, the element-wise development is disordered, and the links of technological interaction are poorly developed. From the side of the synergetic approach, the presence of external perturbations (fluctuations) is observe, which are a condition for the subsequent qualitative change, transition to a higher level of ordering and development [14].
## CLUSTER APPROACH

### DEVELOPMENT PL (EVOLUTION OF DECISIONS OF LOGISTICS, PARTIES AND OWNERS)

| ORIGIN | SYNERGISTIC APPROACH |
|--------|----------------------|
| 1. NASCENT |
* existing base -
  - development;
  - reconstruction;
  - formation of a new base
  - the formation of the center of gravity |
| CHAOS |

### MATURITY

| 2. GROWING |
| The expansion of borders, the development of its own infrastructure, and the integrated development of the 2-PL territory (an independent logistics solution) are the first manifestations of the multiplier effect |

### STAGNATION

| 5. DEVELOPING (QUANTITATIVELY) |
| Expanding the composition of participants and the range of services, attracting third-party resources, the emergence of leased facilities and infrastructure, the integrated development of services, 3-PL (third-party logistics), maximizing the multiplier effect, the integrated development of service + territory |

| 6. DEGRADING |
| The decline of the existing transport hub and the transfer of the center: |
* To a new area of own origin / local origin / third-party origin;
* To a new, to an existing larger object (absorption);
* To a new, promising point of interaction between modes of transport |

### ORDER

| 4. DEVELOPING (QUALITATIVELY) |
| Expanding the composition of participants and the range of services, attracting third-party resources, the emergence of leased facilities and infrastructure, the integrated development of services, 3-PL (third-party logistics) |

### DEGRADATION

| 3. SUSTAINABLE GROWING |
| Expanding the composition of participants and the range of services, attracting third-party resources, the emergence of leased facilities and infrastructure, the integrated development of services, 3-PL (third-party logistics) |

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**Figure 4.** Development of the stages of the transport node according to the evolutionary-functional approach.
The stages of “maturity” according to the cluster approach are proposed to correlate the bifurcation stage according to the synergetic approach. The two central blocks reflect the stages of growth and sustainable growth to levels two and three PL, respectively. There is a consistent expansion of the composition of participants and the range of services; the first manifestations of the multiplier effect are observed [15].

The difference between the stage of "growth" and the stage of "sustainable growth" is the focus of integrated development - the territory in the first case and service in the second case, respectively. For the synergetic approach, this corresponds to the “bifurcation” stage. The main property of the bifurcation point is the unpredictability of subsequent development. An irreversible change can occur both in the forward and in the opposite direction, as illustrated by the dotted arrow, which returns to the stage of chaos. If the node in its development successfully passes the stage of sustainable growth, then the final stage of maturity is qualitative development (as opposed to the initial quantitative). This stage corresponds to the third stage according to the synergetic approach - the stage of "order".

The stages of stagnation in the cluster approach also correspond to the stage of order in synergetic. There is a cyclical development associated with a new appeal to quantitative growth, different in scale from the previous stage. At this stage, integration (mutually equal penetration, merger or absorption by a larger object) or metamorphosis into a larger object can occur. The result of development at this stage is the formation of a large facility and infrastructural conditions for accessing the city = >> region = >> transport corridor chain [16].

The stages of degradation according to the cluster approach correspond to chaos according to the synergetic approach. At this stage, the main load of technical specifications is transferred to a new area, local or third party origin, or to a new promising point of interaction between modes of transport.

This classification (Figure 5) is valid for a transport node located at any stage of evolutionary-functional development. An evolutionary-functional approach can become a tool for determining the stage of development of the logistics of any transport nodes, taking into account the results of fundamental research for the transport industry.

An example of the described theoretical model of the evolution of a logistics facility can illustrate the experience of a logistics platform such as Venlo Trade Port (Venlo, Netherlands) [17].

![Figure 5. Illustration of a model for the development of logistics facilities (using the Venlo Trade Port as an example).](image-url)

An example of the described theoretical model of the evolution of a logistics facility can illustrate the experience of a logistics platform such as Venlo Trade Port (Venlo, Netherlands) [17].
a perishable goods storage complex with an area of about 130 hectares; and the MARANGONA Innovation Zone (Science and Technology Park) covering an area of about 100 hectares.

Stage 3 — the formation of an agro-industrial zone (ZAI UNO) with an area of 600 hectares, 600 resident companies; industrial area (ZAI DUE), an area of 100 hectares, 120 resident companies.

Stage 4 - (currently achieved): “Quadrante Europa Freight Village” is an integrated logistics services center with a terminal for combined transport services. The logistics facility has an infrastructure that allows comprehensive customer service, including a network of manufacturing enterprises, distributors, as well as freight forwarders and other logistics intermediaries. A “logistics activity park” has been created, with more than 100 firms and 1800 employees.

4. Conclusions
In the case of the creation and implementation of new projects, the evolutionary development of the logistics facility from scratch becomes somewhat different. For different objects, obviously, the stages of development can be different (we are talking about the duration of each stage), but in general, evolution is typical. On the example of a transport hub in the port of Ust-Luga [18], the following stages of the completed functional and logistic development can be distinguished:

1. construction of individual elements (preparation of a mooring wall, construction of a railway station, commissioning of the first 4 terminals under the project);
2. enlargement of the logistics facility (commissioning of 4 more terminals);
3. connection of auxiliary elements (the formation of an industrial-industrial park, housing construction, integrated development of the port area);
4. regionalization, clustering (obtaining a multiplier effect, attracting resident companies, etc.).

The synergy effect of using the cluster infrastructure is to reduce the individual costs of its formation for each individual cluster member, as well as to reduce the costs of its further maintenance and use. In this case, we are talking about objects of transport, energy, engineering, housing and social infrastructure for the development of the cluster. Joint use by participants of a cluster of logistics infrastructure, energy systems, information networks, marketing developments, etc. allows you to get higher quality services at a lower price. In addition, due to territorial proximity, the availability of counterparties increases and transaction costs are reduce, i.e. positive synergistic effects of territorial agglomeration are manifest.

It should be note that the multiplier effect of the work of the logistics facility in the coverage area could be total, local or complex. At the same time, the effective development of transport hubs can have an effect both in industries related to transport and warehouse logistics, and in industries unrelated to transport and warehouse logistics. In unrelated industries, this is a social and financial effect. In related industries, the type of the recipient of the results divides the types of effects - these are effects for the railway carrier, region of presence, transport and logistics and production company. In addition, within each of the identified areas of efficiency, the same logistics facility can initiate not just one, but a number of related changes [19-22].

This approach, therefore, will reflect a whole range of parameters important for the logistics of transport hubs: the infrastructure basis, geography, service focus, regional development and development of logistics solutions. The parameters taken into account in the proposed approach are essential for the further configuration of logistics systems, transport nodes, and terminal networks of any complexity.

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