# THEORETICAL ASPECTS OF INTERACTION MECHANISMS IN TRANSPORT SYSTEMS

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## ABSTRACT

*The article investigates fundamental mechanisms of the functioning of transport systems. Interaction of participants of transport processes is predetermined by competition and coordinated activities. They can lead to different economic outcomes, but they are always based on interdependent connections and relationships – mechanisms of systemic effects. The authors propose a conceptual model of display of interaction mechanisms that characterizes methodological principles of competition and integration of various transport modes at the transportation market.*

## ENGLISH SUMMARY

**Background.** *Traditionally, the interaction in transport systems refers only to interaction of different modes of transport. However, this scientific-practical category is broader in its content and meaning. And today, following deep integration of all modes of transport and transport systems at various levels for the sake of improving the efficiency of their joint activity it is necessary to justify more accurately theoretical propositions that guide the globalized practice.*

**Objective.** *The objective of the authors is to investigate fundamental mechanisms of transport systems functioning and to propose a conceptual model of display of interaction mechanisms that characterizes methodological principles of competition and integration of various transport modes at the transportation market.*

**Methods.** *The authors use system and fuctional analysis, descriptive method and comparison, mathematical apparatus, methods of solution of optimization tasks.*

**Results.**

**Needs and criteria**

*Many domestic scholars and practitioners at different stages of development of the transport industry and transport science contributed significantly to the development and implementation of the principles of operation of the transport system as of an integrated economic complex. System aspects of transport functioning were within eyeshot of E. V. Kazansky [1], V. N. Obraztsov [2] and other researchers. Since the mid 50-ies of the last century, this research theme was elaborated in Institute of Complex Transport Problems.*

*The main reason for the need to achieve interaction between different modes of transport mostly refers to limitations on the scope of their efficient use, because each mode has both advantages and disadvantages.*

*There are many criteria for comparison of transport modes: transportation cost, comfort, cost of insurance, transportation speed, traffic frequency, the safety of passenger transportation, cargo safety and others [3]. The most common evaluation criteria are: cost, speed, transportation safety.*

*It is believed that none of transport modes can provide the best performance simultaneously on all three criteria. For example, water transport is safe, cheap, but slow. Air transport provides high speed of communication, but the cost of transportation of goods and passengers is still high. If there is a fast and cheap transport mode, the question arises about the safety of movement. While ensuring an adequate level of security selection of transportation type is based on either economic or temporary factors.*

*Technical and economic characteristics (advantages and disadvantages) of various modes of transport determine the area of their efficient use, limit their own capacity and stimulate the desirability of their interaction.*

*In general scientific sense, interaction is a natural form of existence of any objects and any activity.*

*From a fundamental point of view interaction in transport systems should be considered in two aspects that characterize two forms of realization of their interaction:*

*1. The mutual action can appear in mutual effects of individual components of transport systems on each other, which leads to changes either in themselves or in their performance. The most common example of such cooperation is competition between different modes of transport or transport companies.*

*2. Mutual action may become apparent during mutually coordinated activities of individual components of transport systems, aimed at improving their overall effectiveness. To be admitted that different modes of transport can deliver goods jointly by combining traffic on some sections of the route.*

*It is necessary to distinguish the concept of «interaction in transport systems» and «interaction of transport modes». The interaction of transport modes is a special case of interaction in transport systems.*

*The most important point for cooperation in transport systems is that it assumes the function of a core mechanism by which parts of the system are combined in a certain type of integrity, followed by integration (systemic) effects – for example, in the form of lower costs, reduction in delivery time, etc.*

*Integration (systemic) effects are formed not as a result of any interaction in transport systems, but only on the basis of (or subject to) mutually coordinated activities of their parts.*

**Regularity of integrity**

*Its main difference is to act as a main regularity for systems of any nature. Regularity of integrity (emergence) is manifested in the appearance of new integrative qualities in a system, which are alien to its components [4]. Integrity of the system is determined by the following two rules:*

*1) The properties of the system A are not just the sum of properties of its constituent elements a:*

$$\{a_1, a_2, a_3, \ldots a_n\} \subset A, \quad (1)$$

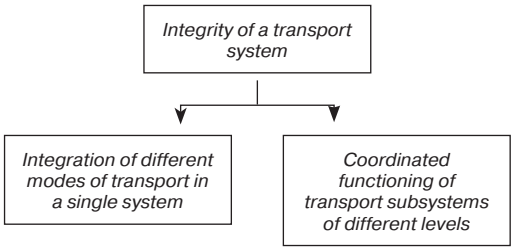
$$A \neq \sum_{i=1}^{n} a_i, \; i = (1, 2, \ldots n); \quad (2)$$

*2) the properties of the system depend on properties of its constituent elements:*

$$A = f(a_i). \quad (3)$$

*System and integrity are two inseparable concepts. The system is considered per se as long as its elements as a result of interaction provide more than if they act separately.*

*Conditional difference between the effect of system performance and the sum of effects of its elements, acting separately, is a value of additional systemic effect E:*




***Pic. 1. Ways of forming regularity of integrity in transport systems.***

$$E = A - \sum_{i=1}^{n} a_i. \qquad (4)$$

*Opposite with respect to the integrity of the system is a state of physical additivity (summativity) when its components do not form an additional systemic effect as a result of joint activity. This «system» is a usual «sum» of its parts, and effectiveness A of such a set of objects is equal to the effectiveness of any system after its «decomposition» into its component parts $a_i$;*

$$A = \sum_{i=1}^{n} a_i. \qquad (5)$$

*For formation of integrity a transport system requires effective interaction of its parts. However, the process of combining elements into an integrated system is contradictory. Any evolving system – technical, social, etc. (transport is deemed to be socio-technical system) is simultaneously striving for integrity and additivity.*

*On the one hand, the combination of elements in a system usually leads to the loss by the elements of their properties, which are inherent outside the system. That is, the system somewhat suppresses the independence of its elements. Therefore, in complex systems the striving for additivity can be observed. This trend is typical for transport systems, in which there are almost always manifestations of competition between different modes of transport.*

*On the other hand, combination of elements in a system provides them with additional opportunities, that is considered as an incentive to build and maintain the integrity of the system. For example, when individual modes of transport do not compete, but consistently distribute areas of activity, concentrate their efforts on them, it gives them an opportunity to reduce their costs and improve overall performance.*

*Integrity of any system is provided by a unique mechanism, which is based on systemic relationships and processes of interaction between its elements (components, subsystems). The structure of transport systems has a complex and multi-level structure. Therefore, their integrity will be maintained:*

*1) as a result of integrated activities of various modes of transport;*

*2) and because of the coordinated operation of transport subsystems at different levels.*

*Accordingly, there are two ways of formation of systemic effects (integrity property) in transport systems:*

*1) integration of transport subsystems of different modes of transport (or simply – the integration of different modes of transport);*

*2) the coordinated functioning of transport subsystems of different functional levels [5].*

**Integration into an integrated system**

*Ensuring the integrity of transport system by integrating different transport modes into an integrated system in the process of mutually coordinated activities is an important condition for improving the efficiency of operations of transport companies. The operation of transport industry on the basis of uniform principles makes it possible to receive an additional systemic effect that taking into account the cross-sectoral nature of transport increases the competitiveness of entire national economy.*

*It means that mutually coordinated activity of transport is a «mechanism» by which they are combined (integrated) into a single system to improve the efficiency of joint transport activity due to efficient use of its advantages and reduction of the impact of their inherent disadvantages.*

*It is necessary to distinguish the concept of «integrated transport system» and «integrity of a transport system». The term «integrity of a transport system» describes a specific principle of organization of joint activities of the various modes of transport; as a result the industry receives an additional effect, as a rule, by reducing total unit costs. Moreover, such an effect cannot be achieved by any mode of transport, acting in isolation. For example, delivery of joint cargoes in mixed traffic with the use of transport units and their transportation by different modes of transport in some parts of the route provides a low cost service as compared with direct traffic. Therefore, the principle of integrity of a transport system can be considered as a prerequisite for formation of system property which is integrity of a transport industry.*

*Integrity in the operation of transport modes provides the following effects for the transport system:*

*• acceleration of flows of goods and passengers, and the reduction of transport costs for the economy;*

*• strengthening links between regions of the country;*

*• increase in the competitiveness and efficiency of other sectors of the economy (due to the reduction of the part of transport costs in the final cost of the product);*

*• growth of entrepreneurial and business activity;*

*• increase in availability of transport complex services to the public;*

*• increase in the competitiveness of transport system at the international market of transport services and implementation of its transit potential [6];*

*• effectiveness of emergency services, civil defense, reduction of the risk of terrorism;*

*• improvement of the investment climate and development of market relations in the transport complex.*

*The term «integrated transport system» describes a state of the transport sector, in which its operation (with unequivocal «integrity of modes of transport») achieves the highest performance in terms of transport servicing the needs of the economy and the population in accordance with established criteria and by the efficient use of resources of all modes of transport during their interaction.*

*The efficiency of transport systems is evaluated by various criteria: low costs, complete satisfaction of the demand, minimum impact on the environment, etc.*

*On the basis of the theoretical positions the following definition can be offered: an integrated transport system of the country is a set of various modes of transport interacting effectively regardless of ownership and departmental subordination, providing handling operation, transportation of people and goods with the use of modern advanced technologies, the most complete satisfaction of demand of the population and cargo owners as for transport services by optimizing time and total cost of transportation.*

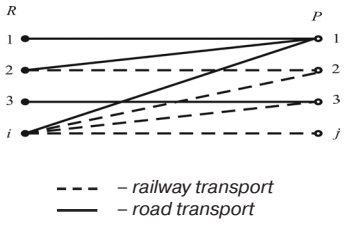
**Levels of interaction**

*Interaction in transport systems is carried out for the purposes of:*

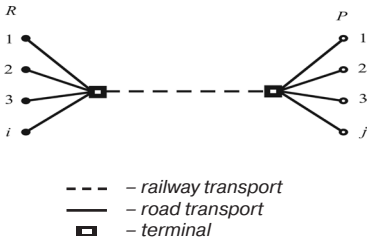
*• provision of better services to clients;*

*• increase in efficiency of individual modes of transport and carriers;*

*• growth of traffic speed due to redistribution of traffic flows within the road network;*




**Pic. 2. Scheme of alternate substitution.**




**Pic. 3. Scheme of rational addition.**

• attraction and retention of individual customers when they need delivery of cargo or passenger «from door to door», and an individual carrier for objective reasons cannot carry out the whole shipping process alone.

Under any of the motives of interaction between different modes of transport an individual transport company is «forced» to concede its share at the transport services market, or any part of the transport operation in the supply chain to other carriers (its competitors).

Methodologically, it is advisable to distinguish two levels of interaction in the transport systems:

1) interaction at the transport services market (economic level);

2) interaction in the technological process (technological level).

**Interaction at the economic level**

Such interaction in transport systems is divided into two types: alternative substitution and rational addition.

***Alternative substitution***

When individual modes of transport mutually influence each other through the efficient use of its competitive advantages, taking into account operating conditions and individual requirements of customers, they offer alternative and more efficient transportation options. For example, road transport provides a greater effect as compared to railway transport in transportation of small shipments over short distances.

In an alternative substitution interaction of transport modes is somewhat abstract, as the transportation process is performed by only one mode (direct communication). Assume, there is a plurality of consigners R and consignees P. Alternative substitution means redistribution of orders for transportation between different modes of transport with account for cost-effectiveness of each scheme of delivery of goods for each route and existing restrictions. As a rule, optimization methods of linear programming are used for selection of schemes of operations' redistribution on routes.

***Rational addition***

Carrying out of mutually coordinated activities by various modes of transport via rational allocation of operations in the sections of the transportation route provides both increase in the effectiveness of their joint activities, and better results for their clients.

Modes of transport efficiently complement each other in the implementation of a single process of transportation (mixed traffic). It is possible to distinguish various options of mixed traffic, such as road-rail piggyback traffic [7]. In this case, the entire transportation route is divided into separate sections, which are serviced by one mode of transport. And combination is organized usually in such a way that the total cost of transportation is minimum.

Mixed traffic can also be used when the work of a single mode of transport is not possible for objective reasons. For instance, the need for land-water communications occurs in the presence of water obstacles impeding the use of land transport.

**Features of cost optimization**

***Within alternative substitution***

Here, the consignor has the ability to select any i-th mode of transport for transportation of the consignment of Q volume over transport distance L. In this situation, the objective function of the optimization of costs C* for transportation is formulated as:

$$C^* = \min_{s_i} C(Q, L, s_i);\ i \in I,\ s \in S, \qquad (6)$$

where $s_i$ is the cost of transportation of cargo unit on the i-th mode of transport, when $i = \{1, \ldots, n\}$.

The problem formulated in that manner doesn't set up limits explicitly, although in a particular situation additional parameters may be taken into account for its decision: limits of transportation costs, delivery time, and others.

The value of the function $C^*$ in the expression (6) is dependent on a variable $s_i$. For this case minimization can be performed by complete enumeration of possible solutions and selection of the minimum one out of them. Given the small dimension of the problem (number of modes of transport, type of rolling stock that can be used to transport cargo in a given direction), the solution can be found within a reasonable time, even without program calculations, but the development of computer software to find solutions will speed up the calculation process.

The cost of transporting cargo unit $s_i$ (freight rate) depends on the operating costs, speed of communications, safety of transportation, and other factors. Tariffs are formed from the condition of the excess of the unit cost $C_{unit}$ per unit of cargo transported (vehicle capacity) q or performed transport work R. By increasing the load capacity of the vehicle and, as a consequence, the volume of cargo there is also a decrease in unit costs per unit of transport work. However, this dependence is individual for different modes of transport, as well as for different types of rolling stock of one mode of transport (for example, truck of low and high capacity).

The decrease in unit costs with increase in the volume of transport services provided (or transported cargo) due to increased load-carrying capacity of the vehicle occurs due to the decrease in fixed costs per unit of transported cargo. Therefore, modes of transport with low unit costs have usually lower rates. Accordingly, high unit costs are associated with a high value of fixed costs attributable to small volume of traffic: wages of drivers, zero runs, overhead costs, etc.

In the entire range of load-carrying capacity a mode of transport is selected, whose rates (lower unit costs), all other things being equal, will be lower. This provides the minimum value of costs C*, formed during freight transportation. Therefore, this mode of transport with load-carrying capacity q enables to carry goods rationally in volume Q.

The approach is idealized, since it ignores the possible dependence on unit costs of transport distance L, type of cargo and other transportation conditions. Fur-

*thermore, the cost factor does not always prevail, because with low cost of transportation speed is usually also low.*

***Within rational addition***

*Mechanism of formation of a systemic effect on the interaction of various modes of transport in the form of rational addition is generated in the form of reduction of total costs for combined freight transportation cargo by several modes of transport.*

*Combined (mixed) traffic is often applied when there is no possibility to use directly the services of more effective, from an economic point of view, mode of transport, such as rail, if there are no approaching lines.*

*In mixed traffic the entire transportation route L is divided into sections of an amount j = {1, ..., m}, at each of which a task can be performed by a single i -th mode of transport over the appropriate distance $l_{ij}$. In this case, the transportation tariffs of i-th mode of transport in sections of varying lengths may vary (differentiation by distance). Therefore, a variety of tariffs $s_{ij} \in S$ is used for the i -th modes of transport differentiated by transportation distance $l_{ij}$ on the j -th sections.*

*Then the distance of transportation of cargo in intermodal traffic by i -th mode of transport at all sections, where it is used, will be:*

$$\sum_{j}^{m} l_{ij} = L_i,\ j = \{1, \ldots, m\}, \qquad (7)$$

*and conditions of continuity of transportation route are formulated as:*

$$\sum_{i=1}^{n}\sum_{j=1}^{m} l_{ij} = L,\ i \in I, j \in J. \qquad (8)$$

*Expression (8) can be considered as a limitation of the optimization task.*

*Optimal variant is formed by the combination of transportation routes of i -th modes of transport of cargo in the volume $Q_{ij}$ over distance $l_{ij}$ at a cost $s_{ij}$:*

$$C^* = \min_{l_{ij}, s_i} C(Q_{ij}, L_i, s_{ij}),\ s \in S, \qquad (9)$$

*with restrictions on the distance (8) and the volume of transportation:*

$$\sum_{i=1}^{n}\sum_{j=1}^{m} Q_{ij} = Q,\ i \in I, j \in J. \qquad (10)$$

**Interaction at the technological level**

*At this level interaction of transport modes involves their joint participation in the process of transporting goods or passengers within the effective variant of rational addition formed at the economic level.*

*If at the economic level, the interaction is abstract enough, then at the technological level it becomes more real and involves coordination of various modes of transport mainly in the framework of an integrated transportation process, which is especially clearly manifested in the transport hubs.*

*The effectiveness of the implementation of each rational option of interaction between individual modes of transport depends on the coordination of parameters of such interaction. Traditionally we distinguish economic planning, technical, technological, organizational, legal, information parameters [8].*

*Economic planning parameters include coordination of: size and structure of vehicle fleet; volume and frequency of traffic; tariffs and cost of operations of the transport process, other parameters of joint activities.*

*Coordination of technical parameters includes: unification and standardization of: vehicles, infrastructure, handling equipment, containers, creation of combined terminals, unit load devices, etc. Transport organizations should coordinate with freight owners parameters of rolling stock in size, load-carrying capacity, capacity, availability of equipment with account of cargo properties and conditions of its transportation.*

*Coordination of technological parameters is carried out in order to ensure the continuity of the transportation process and includes: coordination of freight and transport operations; traffic organization of different modes of transport within combined schedules; common technological processes of different modes of transport in cargo transshipment points and transfer of passengers; use of common information exchange systems on the location and arrival time of ships, cars, automobiles; coordination of schedules and timing of modes of transport, the order of operation and workflow of consignors, carriers, consignees and transport hubs, etc.*

*Coordination of organization parameters of transport modes interaction is an extremely difficult task due to the incompleteness of institutional and structural reforms, preservation of departmental and territorial fragmentation, lack of full competition [9]. To solve current organizational and coordination tasks integrated structures are usually created, with authority to control and regulate the transportation process: traffic control services, transportation control centers, etc. Strategic issues can be solved by a variety of integrated structures: alliances, unions, associations, strategic partnerships, bringing together both national and international transport organizations.*

*Legal parameters of coordinated interaction of transport modes are determined with account for requirements of current legislation. Transport organizations on a contractual basis fix legal conditions for joint participation in a single transportation process: rights, duties, responsibilities.*

*Information resources play a key role in the effective organization and operational management of the transportation process, as well as the coordination of all parameters of coordinated interaction of transport modes, so they have intersystem character.*

**Competition at the service market**

*In the most general sense, competition refers to the proposal of:*

- *the same product (same service);*
- *at the same market (place);*
- *to the same buyer (client).*

*Criteria for evaluation of carriers by clients can be: price, duration, safety, comfort and so on.*

*Examples of competitive struggle between carriers:*

*1) Transport companies offer customer transportation of its cargo to the desired route at the same price, but with different duration;*

*2) Transport companies offer customer transportation of his cargo to the desired route of the same duration, but at a different price;*

*3) Transport companies offer customer transportation of his cargo to the desired route with different duration and different price.*

*Competition between various modes of transport is any form of transportation activity, which leads to a change in its conditions or results, including termination of functioning of any business or individual modes of transport as a whole, in particular- bankruptcy.*

*Competition is realized in the form of an alternative replacement of option for transporting cargo by one mode of transport (or carrier) with the variant of the same cargo transportation by another carrier. At the same time the basis for functioning and development of transport services market is competition of independent private transport organizations.*

*The structure of this market involves:*

*1. Services of general purpose – a competitive (free) market with self-financing.*

*2. Services of federal significance (in the case of Russia) – a non-competitive market with state support in the form of budget funding for maintenance and upgrading of systems and facilities, ensuring safe operation of transport (inland waterways and hydraulic structures on them, nuclear icebreaker fleet, navigation and air traffic systems, railway infrastructure, search, emergency rescue and other special services).*

*3. Services for socially important transportation – a competitive market with compensation of losses in connection with the carriage of privileged categories of the population, delivery of products to the Far North areas and equated localities with limited terms of navigation, etc.*

*Depending on carriers' belonging to the national transport system, the competition can be:*

*1) internal – between domestic carriers:*

*• intraspecific – between carriers of one mode of transport;*

*• interspecific – between carriers of different modes of transport;*

*2) external – between transport systems and carriers from different countries:*

*• at the market of foreign operations;*

*• at the transport market of other countries;*

*• at the market of international transit traffic;*

*• at the market of transit traffic for international transport corridors [10].*

*Depending on the conditions of access to the market, there are:*

*• direct competition – at the market there are many independent carriers of both one and different modes of transport (freight and passenger transportation in long-distance and international communications);*

*• competition «for the market» (if direct competition is impossible or is destructive) is organized on the basis of a public competition of operators, the winner of which works alone at the market (for example, in some regions, rail and road intramunicipal and intermunicipal transportation of passengers).*

*Types of competition in passenger transportation sector on regular routes:*

*1) competition on the route – a few carriers serve the same route (a negative impact on the revenue base of all carriers);*

*2) competition between routes -can take two forms:*

*• competition on alternative routes – has a positive impact on service of population and encourages the development of passenger transportation market;*

*• competition on duplicating routes – harms the efficiency of the public transport system.*

**Conclusions.** *The authors investigated fundamental mechanisms of the functioning of transport systems. The authors highlighted different types of interaction of participants of transport processes, which are predetermined by competition and coordinated activities. The authors proposed a conceptual model of display of interaction mechanisms that characterizes methodological principles of competition and integration of various transport modes in the transportation market.*

*Increase in the quality of transport services in the competitive market of transport services is possible due to consolidation of the transport business. This consolidation ismerging of carriers within in a large company to provide services as an integrated operator to customers of a certain market segment. Such an option is allowed in those market segments where the activity of a large number of small inefficient operators reduces standards of transport service and level of safety, interferes with the normal renewal of fixed assets. The state encourages the consolidation of business by enhancing the quality requirements for operators.*

*Keywords: transport system, interaction of transport modes, concept, system properties, transport services market, competition, coordinated activity, modeling.*

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