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Stages of transport corridor development: Mechanisation, robotisation, intellectualisation and digitalisation perspectives

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Abstract

The aim of the article is to investigate the perspectives of transport corridors digitalisation. The subject of the study is rail freight transport.

The authors use the Theory of Inventive Problem Solving (TIPS) methodology, which forms the basis of transport industry development stages: mechanisation, intellectualisation, robotisation (automation) and digitalisation. The transition from one stage to another is shown by the comparison between the two documents of significant importance for Eurasian transport: Agreement on International Goods Transport by Rail and Convention concerning International Carriage by Rail (CIM-COTIF). They are fundamentally different at the stages of mechanisation and robotisation that makes the digitisation of international transport corridors impracticable. The article clearly identifies the factors preventing digitalisation, as well as the ways of its neutralising.

The research proves that a fully digitalised transport will represent an isolated system, aimed at meeting the most predicted part of human demands. The article presents the transport corridors digitalisation model.

The authors state that modern transport is at the stage of automation and robotisation and has not yet approached digitalisation. The pipeline transport is the only transport mode that has closely reached the digital frontier. Railway transport also has favourable prerequisites and perspectives.

Keywords: transport corridor, convention concerning international carriage by rail (CIM), RZhD, digital railway, path dependence.

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Introduction

Experts consider the prospects for the digitalization of transport today rather optimistic. Indeed, unmanned vehicles are already moving on public roads, self-driving locomotives are being tested, the use of mail drones, etc. has become commonplace. However, in our opinion, such examples indicate the intellectualization of transport rather than its digitalization, since it requires a radically different technology of transport connectivity.

The very concept of "transport digitalization" does not have a generally accepted interpretation and, as a rule, is reduced to a list of practical technologies (both in scientific publications and in official documents). Thus, the long-term development program of Russian Railways provides for the transition to the "digital railway" and the introduction of the following technologies: platform solutions integrated with the production systems of Russian Railways; internet of things; big data processing; blockchain; digital modeling; artificial intelligence; a new generation of mobile workstations; electronic document management, etc.[1] The digitalization of transport in this sense looks like a set of digital solutions that do not have a clear systemic integration.

The concept of transport corridors' digitalization is even less defined. For example, Decree of the Eurasian Intergovernmental Council No. 4 dated by January 31, 2020 approved the plan to form an ecosystem of digital transport corridors of the EAEU which includes: a digital map, a reservation system for infrastructure facilities, an electronic international waybill system used for rail and road transportation, etc.[2]

The definition of the European Commission on the development of transport corridors does not add clarity: "An

[1] Decree of the Government of the Russian Federation dated by March 19, 2019 No. 466-r "On approval of the development program of Russian Railways until 2025". http://www.consultant.ru.

[2] Decree of the Eurasian Intergovernmental Council No. 4 dated by January 31, 2020 "On the Formation of an Ecosystem of the Eurasian Economic Union Digital Transport Corridors". http://www.consultant.ru.

international transport corridor is the presence of road, rail, water and mixed modes of transport that operate in close proximity to each other or are remote for many kilometers, but oriented in one common direction" [Efremov et al., 2019].

In this regard, it seems that before anything else the terminological certainty of transport corridors' digitalization is necessary.

1. Terminology and the concept of digitalization

In our opinion, the digitalization of transport corridors can be considered most adequately with regard to the Theory of Inventive Problem Solving (TRIZ), which was developed by the Soviet inventor G. Altshuller [Altshuller, 2011; Shpakovsky and Novitskaya, 2011].

In accordance with TRIZ, any technical system, including transport, in its most expanded form includes the following elements (Fig. 1):

- "working body"; the main function of this element is the physical impact on the object of labor to obtain the desired product;
- "transmission"; the main function is the transfer of energy from the "engine" to the "working element";
- "engine"; the main function is the transformation of energy received from the "energy source";
- "computer"; the main function is to control the "engine", "transmission" and "working body".

If cargo transfer occurs only due to the muscular strength of a person, then from the point of view of TRIZ, this person solely performs the functions of all these elements ("working body", "transmission", "engine" and "computer"). The evolution of this system will take place according to the following algorithm: the appearance of transportation mechanisms leads to the allocation of the "working body" subsystem; the emergence of labor and conveyor division system (including transport) involves the allocation of the "transmission" subsystem; the appearance of motors makes for the allocation of the "engine" subsystem (Fig. 2).

Let us take a closer look at the stages of transport corridors' digitalization in Fig. 2 and clarify the terminology.

1. *Mechanization.* In this study, it is perceived as the addition or replacement of human physical labor by the work of mechanisms according to the algorithm: a person → a mechanism → an object of labor (freight traffic). The mechanism corresponds to the "working body" element in Fig. 1.

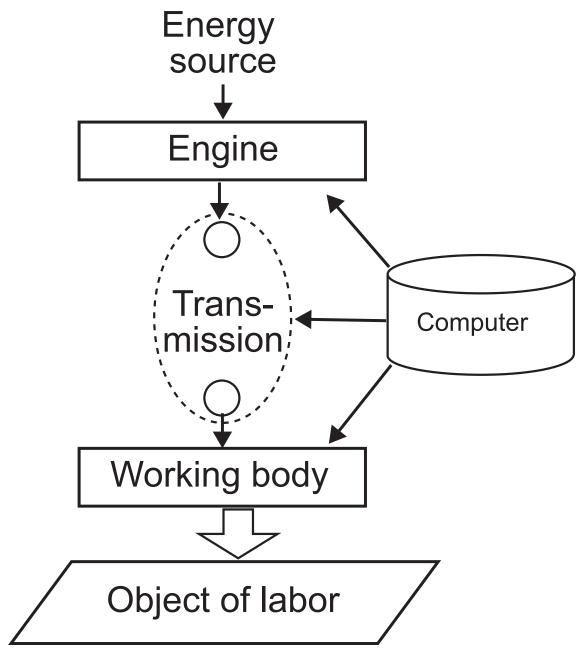
Mechanization is possible if two conditions are observed:

1) labor is of a routine nature, that is, it is repeatedly reproduced according to the same program;
2) the volume of routine work is significant, which makes it appropriate to develop and use special mechanisms.

In the transport industry, examples of mechanization include various types of wheeled equipment, lifting devices, communication lines, etc.

2. *Robotization.* We understand it as a process of organizing a single production chain from physical

Fig. 1. Internal structure of technical system according to TIPS (theory of inventive problem solving)



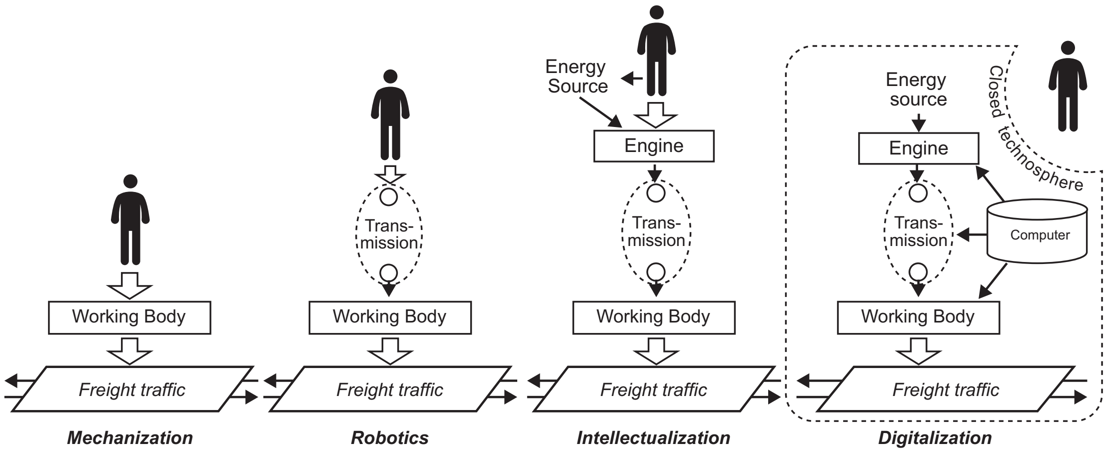
mechanisms that sequentially perform work on the object of labor and are activated by a signal from a certain trigger (for example, by a human command or when a measurement sensor is activated). Such robotic production chains are organized in accordance with the stages of the labor division and correspond to the "transmission" element in Fig. 1, since one or another set of mechanisms is sequentially activated. If the work is carried out only with the help of computer programs, then such a process, in our opinion, should be called automation.

With robotization (automation), in contrast to mechanization, a person transfers the entire production cycle to the technical system during which a number of not uniform in quality operations are sequentially performed on the object. Because of this, the transport process is a kind of conveyor operating according to the principle: a person → an energy source → a mechanism 1 → an object of labor → a mechanism 2 → an object of labor → ... → a mechanism n → an object of labor. The control of the technological process in this case is carried out by mechanisms according to a predetermined and, which is of fundamental importance, an unchanged program.

In the transport industry, examples of robotization can be a car, a ship, a locomotive, as well as railway lines of communication in which a sequence of operations is performed on the flow of goods within the framework of labor system division (transportation, storage, loading/unloading, packaging, distribution, etc.).

3. *Интеллектуализация* Intellectualization in the framework of this article is understood as the transfer of the ability to calibrate and even completely change the program being executed from a person to a technical system (that is, to determine the work scope of the "transmission" and "working body" elements in Fig. 1). As a result, a person is

Fig. 2. Stages of transport system evolution according to TIPS



exempted from participating in the operational management of the transportation process, which is now carried out according to the principle: a person (situational) → an energy source → a computer program → equipment → an object → a computer program → a person (situational). In other words, the transport system in this case is already able to perceive and interpret the signals of the external environment restructuring the entire transportation process respectively.

In the transport industry, examples of intellectualization are systems that can operate without the direct presence of a person: smart traffic control systems, unmanned vehicles, mail shuttles (drones, rovers, etc.), as well as intelligent transport payment systems, analyst robots, etc.

4. *Digitalization,* which in its most simplified form can be understood as the complete removal of a person from the transportation process (that is, dehumanization) and the transfer of all its functions to cyber-physical systems, is "smart systems that include interactive engineering networks from physical and communication components" [CPS PWG Draft , 2015]. In our opinion, these systems should be able to perform at least the following functions:

- forecasting the need for cargo movement;
- advanced planning of production capacities for the physical cargo movement (i.e. renewal, modification or even replacement of the "working body", "transmission", "engine" in Fig. 1);
- combination of production capacities to solve current problems of physical cargo movement;
- control over the transportation process;
- ensuring energy supply;
- adjustment of forecasting, planning and physical transportation processes.

It should be noted that the formation of each new stage in the development of the transport industry from the above (mechanization, robotization, intellectualization, digitalization) does not completely destroy the dominant technology of the previous stage and icludes it as a subsystem.

Digitalization requires the fulfillment of a number of conditions:

1. Complete predictability of traffic flows.
2. Effective tools for neutralizing the instability of the external environment.
3. Information symmetry, that is, a situation in which all participants in the transportation have the same maximally complete amount of latest data.
4. Means of cargo transportation technologically capable of operating in the automatic mode of cyber-physical systems.
5. Significant market demand for systematic and unlimited transportation of homogeneous cargoes.
6. Full complementarity of the activities among all participants in the transportation process. The concept of complementarity will be discussed later.

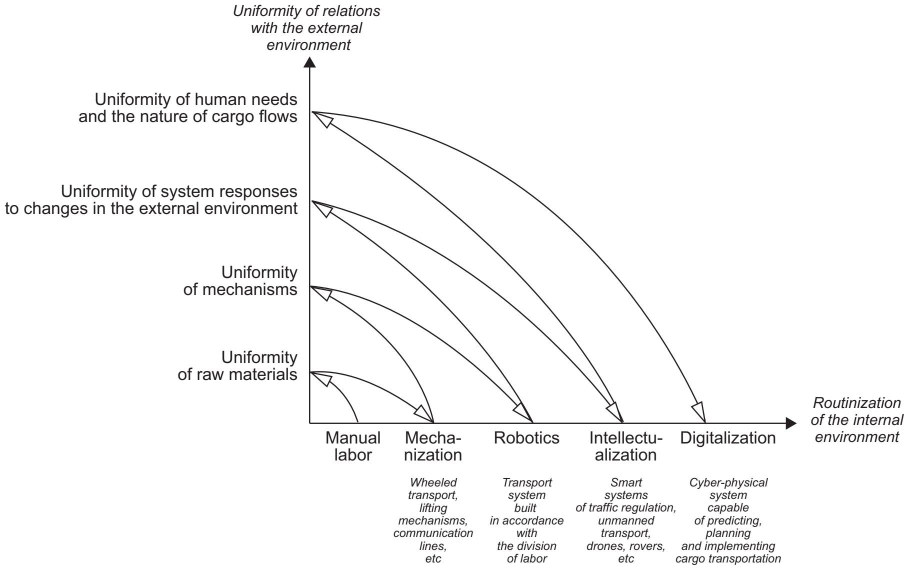
Thus, fully digital transport must acquire all the logical functions of a person, including the control function, because "digit is a control signal in information and computer systems" [Katasonov, 2019]. As a result, the transportation process should be carried out without any human participation according to the principle: cyber-physical system → cargo → cyber-physical system → human (as the final consumer of the cargo).

Based on the foregoing, within the framework of this article, the digitalization of transport corridors is understood as the process of transferring all human transportation functions to cyber-physical systems culminating in the complete dehumanization of the transport process.

In this article, a transport corridor is understood as a geographical route on which the resistance of the external environment to the process of transporting goods is minimal and which, therefore, is demanded by carriers.

The transition to each subsequent, more complex stage in the development of transport corridors occurs with the utmost uniformity, predictability, homogeneity and routine of operations at the previous level. Indeed, by virtue of Sedov's

Fig. 3. Uniformity as a criterion for transport system development



law (the law of hierarchical compensations), in a complex hierarchically organized system the growth of diversity at the upper level of the system is ensured by the restriction of diversity at the previous levels, and, conversely, the growth of diversity at the lower level destroys the upper level of the organization (that is, the system dies by itself) [Sedov, 1993].

Thus, the uniform, routine, often repetitive human labor is capable of giving rise to mechanization; the same set of applied mechanisms is well positioned to generate robotization and automation, immutability and uniformity of the external environment and responses of the transport system – intellectualization, immutability and uniformity of human needs and cargo flows - digitalization.

In view of the foregoing, we can imagine the following stages of preparing the technical system of transport for digitalization (Fig. 3).

Fig. 3 shows that according to Sedov's law achieving uniformity in relations with the external environment (vertical axis) makes possible a qualitative leap in the evolution of production activity (horizontal axis). In turn, the achievement of predictability, uniformity and routine in production opens up new prospects for transferring relations with the external environment to a higher level of uniformity.

In other words, digitalization by default requires one critical condition: the absolute stability of human needs, which results in the linear nature of all changes in the transport system and the full predictability of trade, transport and production processes. This provides the possibility of carrying out transportation without direct and constant human participation.

Of course, this condition is not feasible in the current state of affairs. It is only possible to classify different modes of transport according to their readiness for potential digitalization in terms of two factors (Fig. 4):

- degree of dependence on an unstable external environment;
- freight turnover of homogeneous product units over a long distance. Such homogeneous cargoes include, for example, oil, gas, coal, grain, fertilizers, etc.

Fig. 4. Readiness of different transport modes for potential digitalization

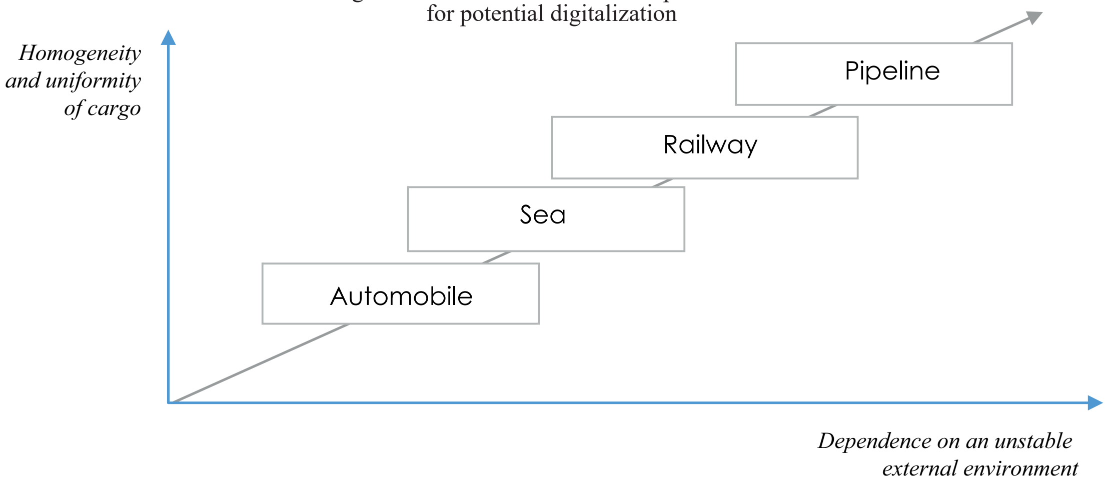


Fig. 4 shows that pipeline and railway modes of transport are most suitable for digitalization, since they use specially allocated channels and ways for moving goods, and they are also focused on working mainly with homogeneous types of goods.

Ideally, for the full deployment of digitalization, impersonal units of homogeneous cargo should move endlessly and en masse along the transport corridors. At the same time, fully digitized transport must be multimodal and global in nature, that is, it must freely cross all spaces, countries and continents. To do this, all participants (including shippers and consignees) must interact on the basis of the same compatible (that is, identical) digital technologies.

2. Non-complementarity of European and Russian railways

To make digitalization become reality, there must be complementarity in the interaction of two or more carriers which in this case means the ability of all participants in the transportation to maintain free circulation of material, information and energy flows among themselves, due to which their own technical systems both remain intact (according to TRIZ, Fig. 1) and preserve the ability to further internal complication.

Complementarity is not observed in interstate railway communication today. This is most clearly manifested in the different gauges on railways and in the difference relating to basic international agreements: the Agreement on International Freight Transport by Rail (SMGS), which is used in Russia, China and a number of other countries, and the Convention on International Rail Transport (CIM-COTIF; often referred to as CIM in Russian literature), which is used in a number of European countries. These agreements have serious differences, and “SMGS clearly protects the interests of the carrier more, while CIM is more in the interests of the sender and recipient” [Kolodyazhny, 2018]. In addition, “CIM provides quite a lot of freedom to the parties to the transport agreement in exercising their rights and obligations. Unlike CIM, the provisions of the SMGS are strictly regulated” [Kolodyazhny, 2018]. Thus, SMGS and CIM have fundamental differences regarding the most important legal aspects: “the terms of the transport agreement, the legal status of the recipient, the rules for service payment under the contract, the acceptance and delivery of cargo, the calculation of the amount and limits of the railway (carrier) liability, the rules for filing claims and lawsuits” [Budzinskaya, 2013]. As a result, “it is impossible to deliver cargo, for example, from Germany to Russia using one waybill. It is necessary to re-register transportation documents” [Budzinskaya, 2013].

In our opinion, the fact of a fundamental difference in document management systems is associated not only with political factors, but has deeper, systemic reasons. Let us consider them in more detail.

It is a common fact that in the world the width of the railway track ranges from 1000 to 1675 mm, and in Europe historically there were railway tracks with different gauges in parallel. Only with the passage of time a single standard for the gauge of 1485 mm appeared, which, "as historians note ... was used by Roman craftsmen who made carts" [3]. However, even today there is still no complete technical uniformity of railway tracks in Europe: “Today, in the EU, three states - Latvia, Lithuania, Estonia - have a 1520 mm gauge, Finland has a 1524 mm gauge, Poland and Slovakia have separate railway lines with a 1520 mm gauge; there are also small sections in Hungary and Romania. We should not forget about the presence of the “Iberian” gauge in Europe - 1668 mm in Spain and Portugal” [1520-1435: prospects for cooperation, 2011]. In addition, it should be noted, that “one of the obstacles to the creation of a single railway network is the lack of technical compatibility between the railway networks of the EU countries. For example, in European countries, various types of alarm systems and contact network voltages are used. As a result, “the creation of a single railway space is still an unattained goal for European countries, which is due to the lack of technical compatibility between the railway networks of the EU countries” [Rynok rail freight traffic.., 2020]. It was only in April 2004 that the European Railway Agency was established to coordinate technical specifications for technical and operational compatibility and traffic safety and to create a competitive European railway system.

At the same time, in Europe, the importance of “rail transport in passenger and freight traffic is relatively small: in 1970–2000, in 15 EU countries, the share of rail transport in passenger traffic decreased from 10.2 to 6.3%, in freight traffic - from 20.1 up to 8.1%” [Rail freight market.., 2020]. Competition from road transport is growing: “...increase in the competitiveness of road transport: market liberalization has created a mechanism in which licensed road carriers freely deliver goods from one EU country to another” [Rail freight market .., 2020]. Road transport in Europe “gained the opportunity (with a license) to deliver cargo between any cities of the European Union countries. At the same time, in railway transport for international transportation it is necessary to conclude contracts and agreements between all countries and railway companies” [Rail freight market.., 2020].

At the same time, competition within the railway system itself is actively stimulated: “by concluding state contracts and ... opening up access to infrastructure and freight traffic” [Rail freight market ..., 2020]. As a result, in Europe "... direct carriers of goods or passengers, whose activities are carried out on the same infrastructure compete with each other" [Rail freight market.., 2020].

The listed facts about railways in Europe suggest that they are an auxiliary mode of transport. Relatively short haul distances provide a competitive advantage to road freight transport, which is able to benefit from economies of scale at much lower volumes than rail. The consequence of this is monopolistic competition in the transportation market.

In our country, initially there was a different situation: “Unlike Europe, in Russia a single standard for the gauge was immediately adopted and since 1851 the “wide” gauge

[3] Railway gauge in different countries. https://pzb-online.ru/novosti/zh/d-koleya-v-raznyix-stranax/#/.

has become a unified gauge during the construction of all railways in Russia itself and in all parts of the empire, and then in the Soviet Union" [1520-1435: prospects for cooperation, 2011].

Let us note this fact: the Russian railway system was designed and created according to uniform standards established centrally. In turn, different widths gave rise to different dimensions of the rolling stock: on the 1520 mm gauge space it is significantly wider and higher than in Europe. Such decisions always have important technological implications for many industries, including, for example, the space industry. So, NASA was forced to take into account the overall limitations of American railways when developing the technology for delivering their aircraft to the launch site - "150-ton segments 12 feet wide to the launch pad." [4]. In other words, the dimensions of modern American spacecraft are determined by the standards of ancient Roman roads - the average dimensions of a wagon and the bodies of two horses.

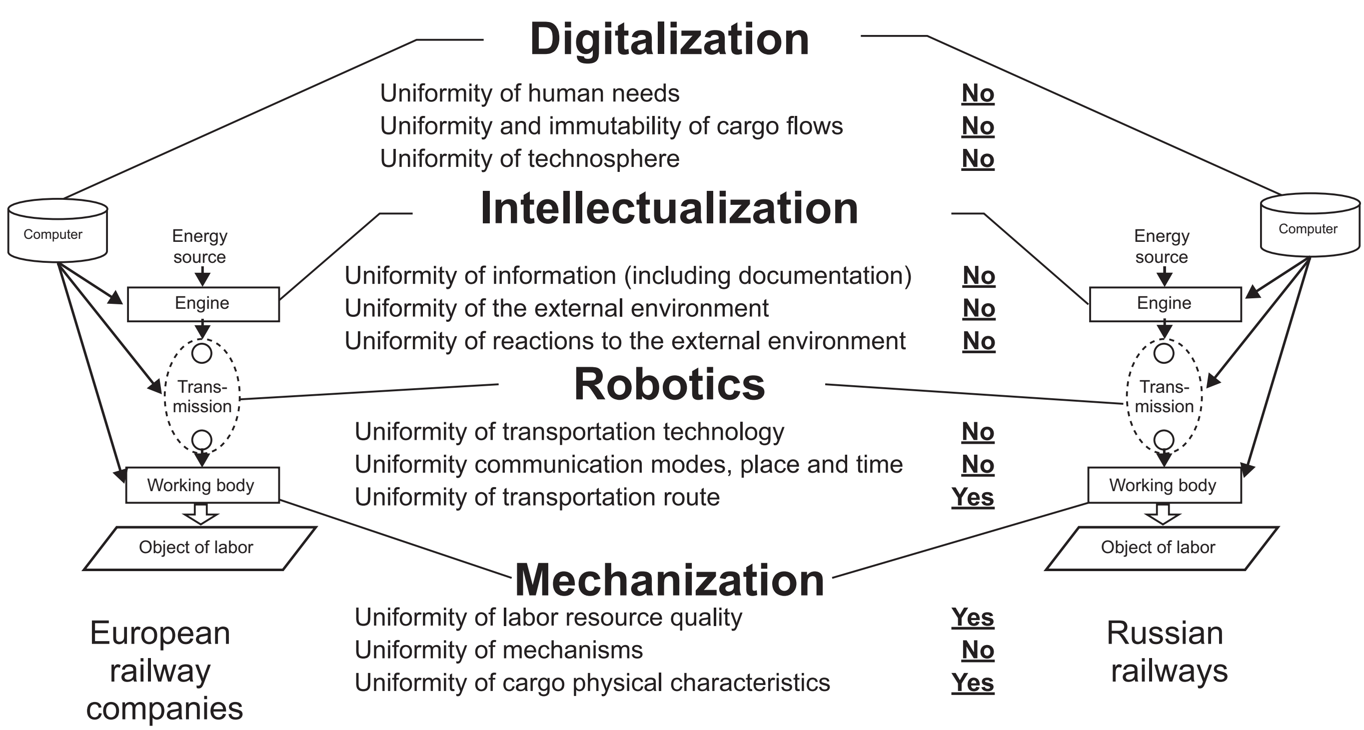
In Russia, however, the special conditions (harsh climate, large territories, significant transportation distances, low density of economic activity) led to the fact that railway lines of communication immediately became the backbone of the entire national economy: communication was carried out mainly with the help of railways focused on large volumes of transportation. Such volumes, in turn, could be provided only by large manufacturers or territorial production complexes. In other words, Russian railways have been and remain the main tool for connecting large technological zones. Due to the vast length of the paths, obtaining a positive effect of scale requires the concentration of all production within one company. Only under this condition a deep division of labor and the efficiency of railway transport is achieved. This property of Russian roads gave rise to a natural monopoly, plus SMGS as a tool for observing its interests.

Thus, the following cause-effect link is observed: different natural, geographical and demographic conditions → different standards of mechanisms, for example, gauges, wagons, etc. (mechanical level) → different technologies for interfacing mechanisms (robotics level) → different ways of reconciling the interests of carriers, sellers , buyers and the state, including in the legal sphere (the level of intellectualization).

In other words, there is a lack of complementarity between Russian railways and European railways on several levels:

1. The level of the natural environment and social institutions: different geographical, climatic, demographic and economic conditions, as well as ways of organizing production. The degree of instability of the external environment (natural and social) in Russia is significantly higher, and the density of economic activity is much lower.
2. Level of mechanization: mechanical technologies are fundamentally different since their inception.
3. The level of robotics: the movement of goods between Russia and Europe cannot be carried out seamlessly, as it requires the constant participation of a person

Fig. 5. Mutual discrepancy of Russian and European railways



[4] Heiney A. NASA railroad keeps shuttle's boosters on the right track. www.nasa.gov/mission_pages/shuttle/flyout/railroad.html.

in the readjustment of wagon bogies for a gauge of a different size.

4. The level of intellectualization: the incompatibility of transportation technologies in Russia and in most of Europe requires a semi-manual process of crossing the border of technological zones, including rearranging wagons to other wagon bogies, semi-manual transmission of information (including in the form of SMGS and CIM) and cash settlements. In addition, the slightest change in the external environment (macroeconomic situation, government activities, international political situation, etc.) requires a laborious process of manual adjustment of the transportation and transshipment process.

Thus, international transport corridors have not yet overcome the stage of intellectualization and in the foreseeable future will not be able to move to the actual digitalization of transportation.

Digitalization as the mainstream of modern transport development requires the complete identity of European and Russian railways at all levels. However, if the activities of Russian and European carriers are modeled using TRIZ, then their non-complementarity can be represented as follows (Fig. 5).

Non-complementarity of Russian and European railways is largely related to the phenomenon that is called the "path-dependence problem" in economics: it is not so important which standard is fixed (for example, railway gauge), but it is important that "then it is impossible to get off this path" [Auzan, 2015]. In this case, the " path-dependence problem " can be understood both in the literal sense (as a historical difference in the gauge width) and figuratively (as the effect of the dependence of new actions on past decisions).

This means that the complementarity of railways and the digitalization of global transport corridors can be achieved on a qualitatively different technological platform (for example, magnetic levitation), which will remove irresolvable contradictions at the mechanical level.

Secondly, non-complementarity is related to the difference in the external environments in which the Russian railway and European railways operate: the higher the instability of the external environment, the more difficult it is to advance intellectualization and digitalization. It is for this reason, for example, that pipeline transport operators prefer long-term contracts rather than pursuing short-term tariff and price maximization.

Thus, it is still very premature to talk about the digitalization of transport corridors. There are some prerequisites for digitalization within the railways (for example, within the Russian Railways), but digital technologies are not complementary for carriers, consignors and consignees, since each of them works in its own technological environment. In addition, government agencies (for example, customs) are not ready either to use the digital documents of these transport entities, or to work in a single information ecosystem. This means that in transport corridors today there are paperless technologies rather than digital ones, since the transportation process still cannot do without human participation.

Conclusion

The globalization of transport flows is an objective global trend. To assess the prospects for the digitalization of transport corridors, the SMGS and CIM agreements are considered. They set an eloquent example of the fact that the digitalization of railway transport is blocked at the level of intellectualization behind which, in turn, unresolvable contradictions between the levels of mechanization and robotics are found.

Different gauges affecting the wear of rolling stock wheel sets, the carrying capacity of wagons, the quality of the superstructure of the track, etc. entail many other consequences, which is especially evident when transporting non-standard cargo. Technological differences determine different economies of scale and, as a result, different institutional environments. All this ultimately results in a different market configuration (seller's market or buyer's market) and determines the prospects for digitalization.

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