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August 2017

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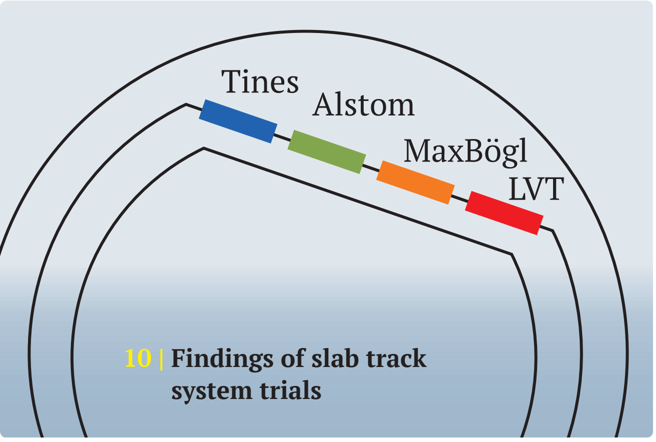


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# Content

# Mixed fortunes for Russian rolling stock manufacturers in 2016

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Russia's rolling stock manufacturing sector experienced a year of tough challenges, new hopes and some records in 2016. Some sub-sectors managed to overcome the difficulties caused by the recent financial crisis. However, others required state support in order to remain in operation.

## Overview

Last year might be viewed as a year of adaptation for the Russian railway rolling stock manufacturing sector. Overall the industry managed to reverse a downward trend in production, which had persisted for the entire sector since 2013, and for some subsectors since 2012, resulting in the growth of production for key products for almost all areas in 2016.

The shipped value index of the rolling stock manufacturing sector reached 5,7bn € in the first 11 months of 2016, an increase of 16.3% compared with the same period in 2015 (fig. 1)[1].

Rolling stock repair and maintenance services were responsible for 33% of the overall shipped value, with freight cars production accounting for the second largest share of the market (fig. 2).

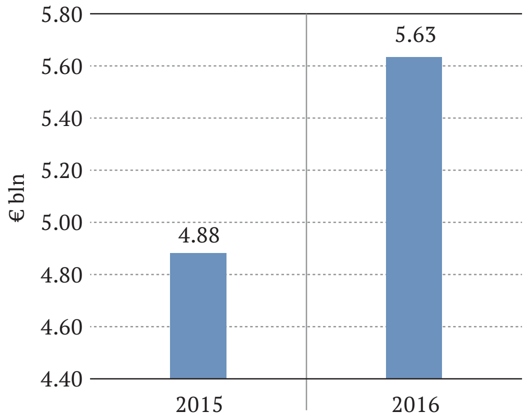


**Fig. 1.** Shipped value by rolling stock manufacturing companies, in billion euro

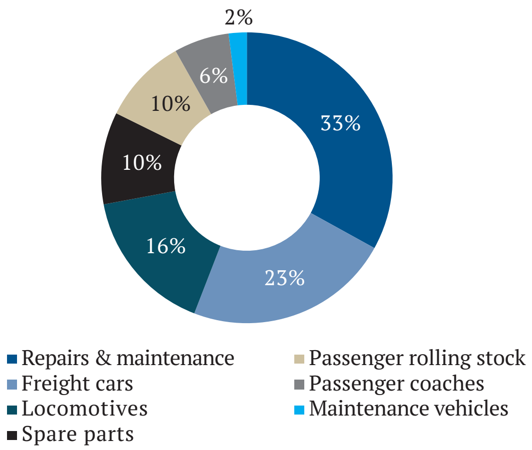


**Fig. 2.** Shipped value breakdown, 2016

## Rolling stock repair and maintenance

Rolling stock repair and maintenance traditionally accounts for the greatest proportion of the rolling stock manufacturing industry and has reported steady growth in the last five years. However, this upward trend altered in 2016 as a result of a number of factors. One of the key reasons was a significant reduction in demand for life-extension repair for rail vehicles, including freight wagons, and locomotives (fig. 3).

The reasons for the fall in repair vary by subsector and depend on the existing situa-

[1] For further information please refer to the article Monitoring of industry status on the basis of IPEM Indices. Results of Q4 2016, pp. 6-14.

tion, and the challenges and objectives of the leading market players. For instance, Russian Railways (RZD), the owner of the largest locomotive fleet in Russia, continued with its optimization program, which is intended to reduce the number of locomotives in the company's fleet, as well as scale back its locomotive service-life extension program. The company's rolling stock maintenance and repair costs are also expected to significantly decrease as a result of this strategy.

Yet another factor that is having sizable effect on the repair business are improvements in the reliability of parts and components for new rolling stock offered by the supply sector, which is increasing the interval between repairs, and reducing maintenance and repair costs.

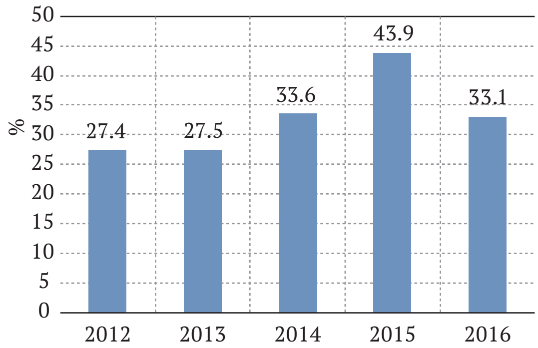


**Fig. 3.** Rolling stock maintenance and repair share of shipped value

## Freight wagons

From January 1 2016, a ban on operating wagons requiring life-extension works and without appropriate certification was instituted. This impacted almost 109,000 wagons in service in Russia, 52.6% of which are gondola wagons.

A freight wagon surplus had almost overnight given way to local shortages of certain wagon types on some routes, particularly during peak handling periods.

Freight wagon manufacturing subsequently began to report an upturn in production from August 2016 onwards. From January to July 16,100 wagons were produced. However, in the remaining five months of the year the 20,500 wagons were manufactured, representing 56% of overall annual production (fig. 4).

However, this has not yet returned the total fleet size to previous levels. Taking into account the withdrawal of life-expired wagons and the introduction of new rolling stock, Russia's overall freight wagon fleet has decreased by 78,200 wagons to 1,072 mln wagons.

Of the total fleet, 48,900 wagons, or 4.5%, have surpassed their expected service life and it is likely that these wagons will be withdrawn in the near future. A further 15,600 wagons will reach the end of their expected service life in 2017, thus bringing the total potential volume of wagons expected to be written off to around 64,500.

The flat wagon fleet accounts for the greatest proportion of this total, with over 20%, or around 15,500 wagons, outdated. A similar proportion of the refrigerated wagon fleet are reaching life expiry, with the service life of more than 18% of the fleet, or 821 wagons currently in operation having been extended. The average wagon age of the fleet is 22.3 years which compares with a design life of 25 years. However, future replacement is in doubt due to the current lack of suppliers in Russia. While flat wagons are currently manufactured by at least six Russia companies, with total domestic flat wagon output exceeding 3,500 units in 2016, currently there is no domestic serial production of refrigerator wagons.

Total output 36,600 wagons. Indeed, freight wagon production will increase in 2017. According to IPEM, 45,000-50,000 wagons are expected to be produced during the year.

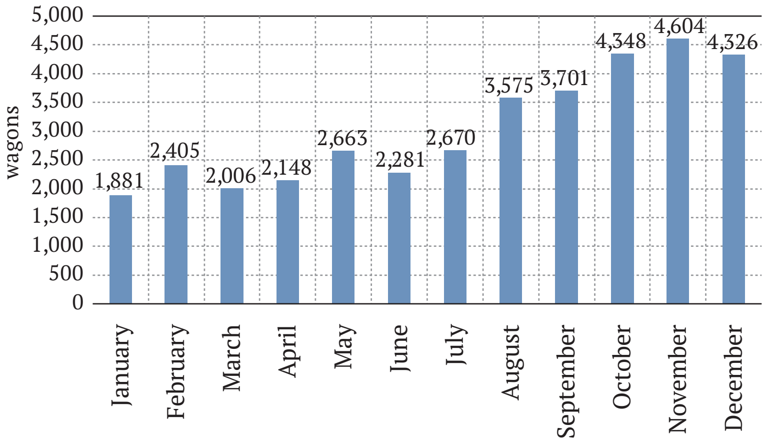


**Fig. 4.** Monthly freight wagon production in Russia, 2016

## Locomotives

In contrast, Russia's domestic locomotive manufacturers are anticipating tougher times ahead. In October 2016, RZD initiated a locomotive fleet optimization program aimed at reducing the overall locomotive fleet from 21,000 to 17,500 units (see Table 1). In addition, new locomotive orders are also expected to reduce. While the 493 locomotives purchased in 2016 was comparable with the 502 produced in 2015, this figure is expected to fall to 450 this year, and RZD is planning to purchase similar quantities at least until 2020.

On the other hand, the locomotive fleet optimization strategy envisages not only reducing the number of units in operation but increasing performance requirements. As a result, RZD is planning to purchase more efficient but expensive locomotives as it develops its heavy traffic development program.

**Table 1.** RZD locomotive fleet in 2012-2016

| | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Diesel Locomotives | 4,157 | 4,128 | 4,210 | 4,237 | 4,202 |
| Electric Locomotives | 10,389 | 10,436 | 10,489 | 10,678 | 10,566 |
| Shunting Locomotives | 6,101 | 6,010 | 5,999 | 5,933 | 5,850 |
| **Total** | **20,647** | **20,574** | **20,698** | **20,848** | **20,618** |

*Source: RZD data*

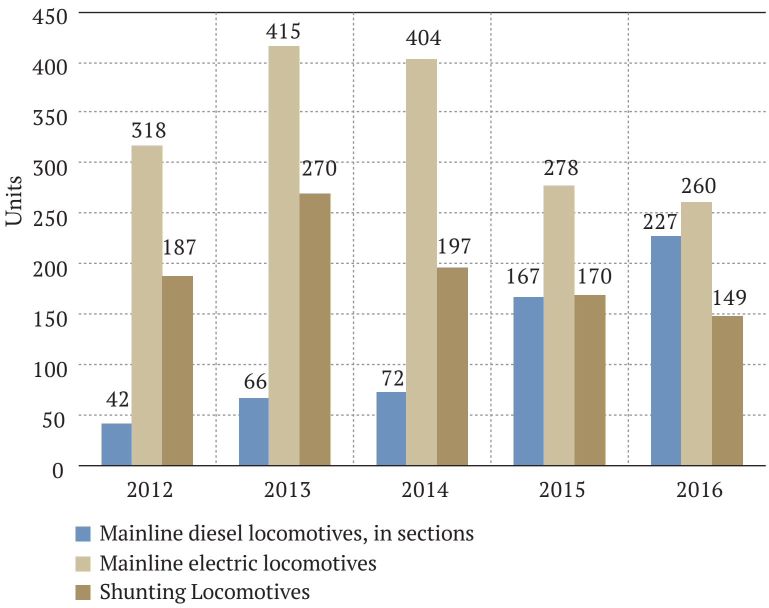


**Fig. 5.** Domestic locomotives output in 2012-2016

In comparison with the 2015 figures, there were no significant changes in the production volumes of mainline electric locomotives and shunting locomotives in 2016. Production of mainline electric locomotives declined by 6.5%, and shunting locomotives production fell by 12.3%.

However, production of mainline diesel locomotives improved by 36% (fig. 5) resulting in an all-time record output of 227 units produced last year. Such a notable increase in production is the result of enhancements to the design capacity of Bryansk Engineering Plant's (BMZ) facilities, the key manufacturer of mainline diesel freight locomotives in Russia. Specifically, production of the 2TE25K$^{M}$ locomotive, which replaced the 2TE116U previously supplied from the Ukraine, began at the plant in 2015.

Projects focusing on manufacturing state-of-the-art locomotives were initiated in 2011 with the start of mass production of locomotives developed jointly by Russian and foreign engineers.

The new locomotives' configuration was heavily reliant on imported parts and components. This became an issue in 2015 when the international political and economic situation deteriorated, resulting in a sharp increase in the cost of production. Access to certain parts and components were also at risk due to the threats to certain imports.

To counter these challenges, an import-substitution program was initiated in 2015 in order to provide Russian manufacturers with extra security by guaranteeing an uninterrupted supply of rolling stock products. A number of previously imported high-tech components have been successfully substituted with an equivalent manufactured in Russia, which has also decreased the cost of production. For example, the cost of manufacturing an EP20 dual-voltage passenger locomotive manufactured by Novocherkassk Locomotive Building Plant (NEVZ) jointly with Alstom was cut by 34%.

## EMUs, light rail and metro rolling stock production

The EMU market has experienced a period of consolidation in recent years with the emergence of two primary manufacturers: Demikhovsky Engineering Plant (DMZ) and Ural Locomotives.

Ural in particular has experienced a rapid expansion of its operations. From the start of production in 2014 when its share of the market was 4.9%, it had grown to hold 40.8% of the market by the end of 2016 (fig. 6).

EMU manufacturing, and the range of products available, has also recently gone through significant changes. In total, 392 EMU vehicles manufactured, a 39.5% increase demonstrated in 2016 vs 2015 level (fig. 7), with many of these new models. For example, DMZ launched serial production of its EP2D dc EMU in 2016, and has so far built 20 11-car trains for Central Suburban Passenger Company's (CPPK) Nakhabino Depot. The company also began production of EP3D ac EMUs for Kazakhstan Railways in 2016, while Ural also delivered its ES2G Lastochka EMUs to the new Moscow Central Ring (MCR) railway. This new link has carried 32.5 million passengers in its first five months of operation.

A newcomer at the EMU market in 2017 has become Tver Carriage Works (TVZ) that is planning to launch a serial production of EG2Tv Ivolga (English: Oriole) EMUs to be operated by CPPK as local express trains on the suburban lines running from Kiyevsky railway terminal of Moscow south-westward.

However, as Figure 7 indicates, the situation is fragile. Unlike Ural Locomotives, which has a long-term contract for the supply of 1,200 EMU cars up to 2023, DMZ is in a precarious position with no major orders. It is also hindered by the approach of the suburban passenger operating companies, which are restricted in their ability to make long-term operations and rolling stock procurement plans due to the short-term funding structure provided by the state. The fact that CPPK is one of the few suburban operators with a 15-year operating contract and is the major customer for EMUs developed and produced in Russia is no coincidence. However, the situation is made increasingly complex by falling suburban ridership in recent years. In particular, CPPK passengers fell by 2.8% to 571 million in 2016. In total, DMZ expects to receive orders for 24 11-car EMUs in 2017 compared with 20 trains in 2016.

It is a similar situation for the metro rolling stock manufacturing sector, the activities of which are heavily linked to the policies of key customer, Moscow Metro, the only Russian metro operator with a long-term development plan. The construction of new lines and renewal of rolling stock used on the existing network provided a significant workload to Metrowagonmash, Russia's sole supplier of metro rolling stock between 2013 and 2015. Production of metro cars was also initiated at Octyabrsky Electric Rail Car Repair Plant's (OEVRZ) facilities, and the company produced 12 cars in 2016.

As a result, in 2016 the metro car manufacturing sector reversed the downward trend in production, which has persisted since 2012. In total, 284 metro cars were delivered during the year, more than 1.5 times higher than in 2015 (fig. 8).

While production has fallen in recent years, Russia's total metro fleet increased by 12.7% between 2010 and 2016, reaching 7,100 cars last year. The age profile of the fleet has also undergone considerable changes. In 2010, around 12% of metro cars were no more than five-years-old but by 2016 this had increased to 22% (fig. 9). This change is down to the active renewal of rolling stock by Russian metros and the withdrawal of older vehicles. A further 2000 cars are expected to be renewed in the next few years.

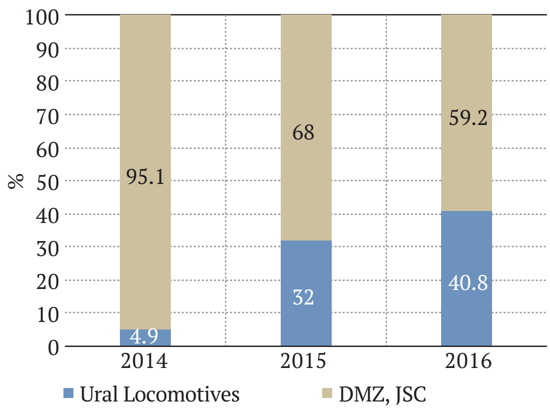


**Fig. 6.** EMU manufacturers' market shares 2014-2016

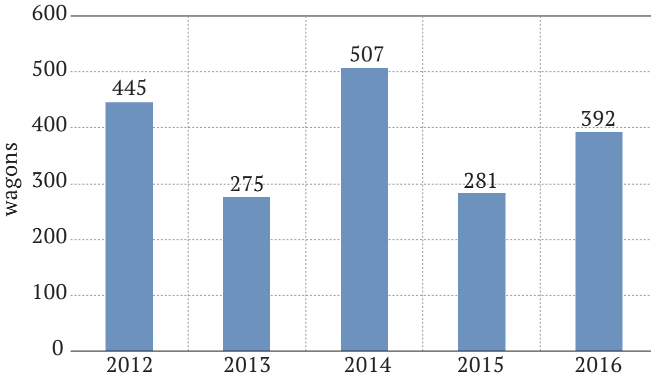


**Fig. 7.** Russian EMU production 2012-2016

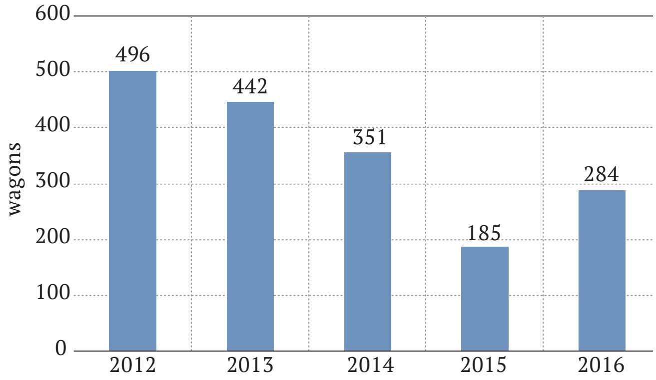


**Fig. 8.** Russian metro cars production 2012-2016

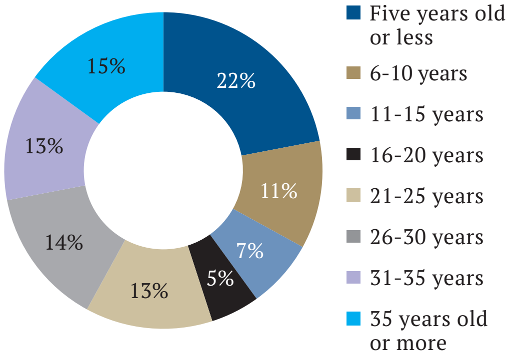


**Fig. 9.** Age profile of Russian metro car fleet in 2015

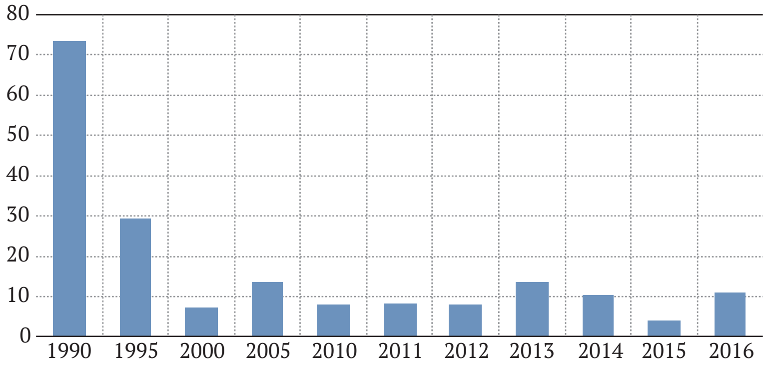


**Fig. 10.** Production of LRVs by Russian companies 1990-2016

Production of light rail vehicles similarly grew by 2.8 times in 2016 compared with the previous year. However, 2015 was the lowest level of production recorded in the post-Soviet period. (fig. 10).

The considerable downturn experienced in 2013-2015 is a direct consequence of funding cutbacks, in particular in the budgets of the regional governments of the Russian Federation. Total tram traffic fell 26.3% to 1.5 billion passengers between 2011 and 2015, while the number of vehicles in the cumulative fleet fell by 5.8% to 8,100 cars, and fleet utilization fell from 63.2% to 62%. [2]

This is the backdrop for a gradual increase in the average fleet age that took place from 2011 until 2015 (fig. 11). The situation is made worse by the lack of long-term programs to support urban rail transport. Furthermore, there is significant difference in the priorities for rolling stock operators depending on their region and the condition of infrastructure. For example, in cities like Moscow and St Petersburg, where there is support for investment, the authorities are more interested in rolling stock which offers a high level of passenger comfort and an attractive exterior and interior design. However, for the majority of regions constrained by a lack of resources, the major priorities are straightforward and cheap maintenance and operation.

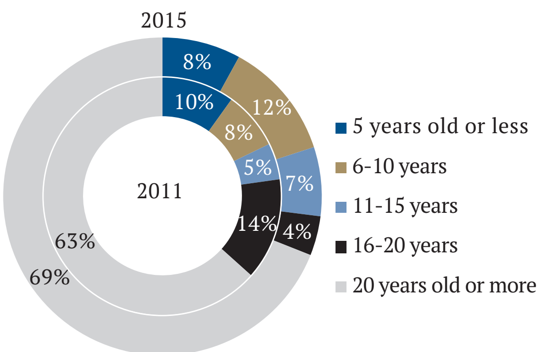


**Fig. 11.** Age profile of Russian light rail fleet in 2011 and 2015

[2] Zakirov S.S., Matrosov V.A., Matveeva E.V. Urban electric transport in Russia. Railway Equipment Magazine, 2016. № 36 (4). p 12–17

## Passenger coaches

The situation is not much better for Russia's passenger coach manufacturing sector, which since 2008 has been in crisis due to the financial situation of its key customer, Federal Passenger Company (FPC).

FPC's ridership fell by 7.5% compared with 2013 to 91.3 million passengers in 2015. The production and procurement of passenger coaches also fell significantly during the same period. However, the situation did appear to change in 2016 when 258 coaches were produced.

Yet this is still some way short of the break-even mark of around 358 coaches for TVZ, the sole manufacturer of locomotive-hauled passenger coaches in Russia.[3] In light of falling orders, TVZ has implemented an optimization policy, cutting its budget, and reducing personnel by 30% from 7,900 to 5,500 people between 2011 and 2016.

The introduction of new rolling stock products like EG2Tv Ivolga EMUs for CPPK and renting out its facilities have become another tools for TVZ in its attempts to resolve the difficulties. The rented facilities have been used by Transport Systems Company to produce its tram producs City Star, Vityaz (English: Knight), Vityaz-M, and Varyag, as well as Admiral trolleybuses. The manufacturer has started this year the deliveries of 300 trams for Moscow.

In response to the situation facing long-distance passenger services, the Russian government has begun discussing prospective reforms in order to modernize in 2017-2019 the network and the level of service available. Investments are expected between 2020 and 2030 and one concept currently under discussion concerns developing both long-distance traffic for distances of up to 1000km and inter-city services.

## Pivot to export

Local manufacturers realize that chances that Russian domestic rolling stock market demand would show any serious growth in the short term are quite low and turn to more aggressive way in their moving into foreign markets. To support these developments, the President's Council on Strategy and National Priority Projects approved on November 30 2016 a priority national project International Cooperation and Export for Industry. The project includes export support package for Russian manufacturers in the long term up to 2025. The objective of this export drive is to reach Russian rolling stock export to $630 million by 2020, and $1,190 million in 2025.

## Conclusion

Despite the generally positive dynamics demonstrated by Russia's transport engineering and manufacturing companies in 2016, it is too early to say that the sector has recovered from the financial crisis. Some subsectors have plans for development both for 2017 and in the long-term. However, the situation for other subsectors is uncertain. The lack of effective long-term demand in some subsectors such as for light rail vehicles and long-distance passenger coaches is putting the very existence of some Russian manufacturers at risk. These companies cannot resolve this systemic issue alone, and they need financial and/or administrative support from the state.

On the other hand, developing the leading subsectors so they can support others could assist the state by supporting its industrial and transportation security in the context of the current troubled global political and economic situation.

[3] 2014 Annual Report of TVZ, JSC

# Findings of slab track system trials

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(Russian R&D Institute of Rail Transport)

In December 2016, tests of four slab track systems - LVT (RZDstroy, Russia), FFB (MaxBögl, Germany), NBT (Alstom, France), and EBS (Tines, Poland) - were completed at VNIIZhT's test facilities in Scherbinka near Moscow [1]. The tests were conducted in accordance with a field test programme and methods validated by Russian Railways (RZD). The four-track line section selected for the trials carried a gross tonnage of 600 million tons throughout the approximately 22 month-long test.

## Pilot slab track technologies

Construction of the pilot slab track sections took place from August 5 2014 until November 20 2014. Initial trials of the pilot line, which were required to stabilize the transition areas on the crushed stone sub-layer, lasted until December 3 2014, at which point the pilot line entered operation.

Each of the four slab track test sections was 75m long, with the total length of the pilot line, including transition areas, reaching 500m.

The track bed for each pilot section was built by a single contractor using the same technology and was incorporated into the test centre's existing secondary loop (fig. 1). After natural soil excavation, two 7m-wide, specially prepared layers were installed each with a 0.04‰ transverse gradient.

The first 50cm-thick soil layer is chemically stabilized using polymer fillers. The mean value of the subgrade stiffness modulus after treatment of the initial layer with the soil stabilization system was 146MPa versus a minimum design value of 80MPa. The static and dynamic test results showed that the modulus of deformation (elasticity) of the stabilized soil performed well.

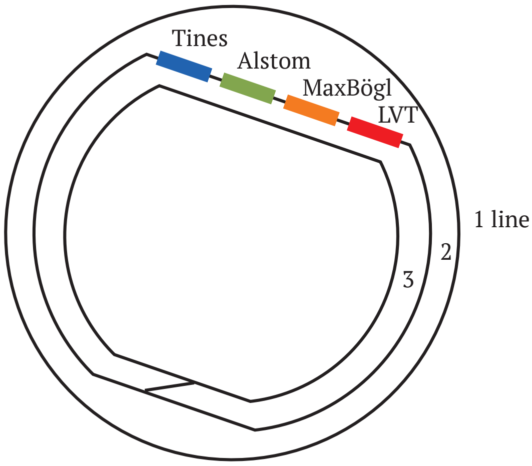


**Fig. 1.** Pilot track sections on the testing facilities

The second layer was 70cm thick and consisted of crushed stone and sand gravel in line with TU 5711-284-01124323-2012. The mean value of the subgrade stiffness modulus for the second layer was 181.7MPa compared with a minimum design value of 120MPa.

The track structures, consisting of the individual slab track sections, [1] were laid by the individual companies.

## Testing conditions

Testing of each slab track type was performed on a branch of the second test loop and took place from December 3 2014 until October 20 2016. A train consisting of a VL-80 electric locomotive and 85 gondola cars with a 23.5 ton axle load was used for the testing, with rolling stock running over the test section at 70 km/h. The line carried 1-1.2 million tons each day, reaching a total of 600 million gross tons at the conclusion of the test.

## Tests results

**Rail gage geometry**

Following the completion of the tests, the rail gage geometry of the sections was in line with safe railway operation requirements. As per the track spotter measurements, the most significant imperfections were:

- widening of gage by 9mm on the transition areas of Tines and MaxBögl
- narrowing of gage - not detected
- twist of 14mm on the Tines slab and 13mm on the Alstom transition zone
- settlement of 14mm on the transition areas of Tines, Alstom, LVT and on Alstom slab
- realigning of 9mm on transition areas of Tines and Alstom, and
- level of 9mm on the Alstom slab.

Additional track gage and level measurements conducted by hand using a measuring gage demonstrated a consistent gage width for all slab track sections. The deviation at 500-600 million tons was from 0.7mm to 0.46mm with mean standard deviation ranging from 0.33mm to 0.04mm, which is mainly attributable to the type of intermediate rail fastenings used [1].

The vertical wear of the rails used in each of the slab track systems was in the range of 0.011-0.024mm, with mean standard deviation ranging from 0.002mm to 0.007mm. Side wear on all slab tracks varied from 0.068mm to 0.118mm with mean standard deviation ranging between 0.006mm and 0.02mm.

MaxBögl's slab track section was found to have the best rail gage geometry. This precision might have resulted from prefabricating the slabs at company's factory rather than at the construction site.

**Rail fastenings condition**

The screw tightening torque values are within specified range for each slab track solution. The following measurements were recorded:

**Tines:** 315-420Nm
**Alstom:** 280-360Nm
**MaxBögl:** 250-400Nm, and
**LVT:** 250-400Nm.

Tines structure had the lowest torque retention loss in the screws used for rail fastenings.

During the tests several defects were reported at the slab track structure, with variations reported between different solutions, and Tines reporting the best results:

**Alstom:** Broken bolts were replaced at 16 of the 100 locations on the auxiliary rails, additional rails which serve to provide extra anchorage on the transition section between track sections. In addition, replacement was required of all 50 of the auxiliary rails fastenings on the slab, and a W300 pad following a failure. There was also a 1-3mm slack between a W300 pad and the concrete slab on all W300 rail fastenings. The imperfect design of the transition section is cited as the cause of these defects.

**Tines:** No defects found.

**MaxBögl:** Failures of three of 600 clips and one of 600 angle guide plates.

**LVT:** Replacement of 64 out of 300 blocks using Schwihag rail fastenings after cracks were found in the anchor dowel hole and fluting, the area beneath the fastening. Additional analysis was carried out in order to identify the causes of the failures and defects.

**Defectiveness of the concrete layer**

The concrete layer defects detected in each of the four pilot slab track sections after each carried 600 million gross tons were not deemed safety-critical. However, they did display some distinctive features.

**Tines:** 54 cracks were found in the supporting block bed; 86 cracks were identified in dowels; seven in the supporting blocks under the rails; and 43 were found in the fluting. In addition, 128 cracks of up to 0.5mm were identified in the structural slab with an additional 24 cracks over 0.5mm. The cracks in the supporting block bed and

**Fig. 2.** Cracks in supporting block bed and in concrete slab (Tines)

**Fig. 3.** Loss of grip between supporting blocks and structural slab (Tines)

**Fig. 4.** Full-width fracture of the reinforced slab (Tines)

**Fig. 5.** Pumping from under the structural slab (Tines)

in the structural slab are shown in figure 2, while the loss of adhesion between the six supporting blocks and structural slab is shown in figure 3. A full-width fracture of the reinforced slab is shown in figure 4 at the location of the largest track pumping. Finally, an active fracture resulting from a hydraulically-bound layer constructed from poor-quality concrete which resulted in track pumping is shown in figure 5.

**Alstom:** 41 cracks were identified on the slab end surface; eight cracks were found in the middle of the slab; five full-width cracks were found in the slab, including slab ends, while 53 fractures of up to 0.5mm, and three over 0.5mm were reported. In addition, bleeding of concrete components at longitudinal joints on the slabs was observed, particularly in wet conditions (fig. 7). Moreover, asphalt joint filler was found leaking from slab strips.

**MaxBögl:** 15 cracks of up to 0.5mm and four over 0.5mm were identified. Some cracks were initiated from the openings for grouting mass. There also were transversal cracks at slab joints (fig. 8). In addition, the filling layer between all slabs broke down causing the failure of slab joints (fig. 9). The grouting mass under slabs was show to have broken down resulting in the splitting of slabs. Bleeding was also reported from concrete components and under the slabs, especially in wet conditions (fig. 10).

**LVT:** 28 cracks were found in rail support blocks; five were identified in blocks along

**Fig. 6.** Cracks in structural slab (Alstom)

**Fig. 7.** Leakage of asphalt filler in slab joints (Alstom)

**Fig. 8.** Cracks in slab and slab joint (MaxBögl)

**Fig. 9.** Slab joint failure (MaxBögl)

bowels; 21 in blocks along the fluting (fig. 11); and 63 cracks of up to 0.5mm and one crack over 0.5mm were identified in the track concrete (fig. 12). In total, 64 blocks using Schwihag fastenings were replaced in 2015 at 240 million tons, with work underway to identify the cause of the failures. Other failures detected include heavy scuffing of the rubber boots holding the blocks in place (fig. 13), and some leakage of scuffing products along drainage gutters. As was reported with the other slab track systems, LVT also reported concrete component bleeding along the longitudinal joint between the track concrete and base plate (fig. 14).

Tines' slab track system was found to have the worst concrete layer condition. This

**Fig. 10.** Leakage from concrete components under the slab (MaxBögl)

**Fig. 11.** Cracks in concrete blocks (LVT)

**Fig. 12.** Cracks in track concrete (LVT)


**Fig. 13.** Rubber boot scuffing (LVT)

**Fig. 14.** Cement components bleeding at the joint (LVT)

was mainly caused by excessive pumping from under the structural slab following the breakdown of the poor concrete layer. As a result, a transverse failure of the structural slab was recorded at the point of the most significant pumping. Moreover, the concrete condition deteriorated following the disintegration of the track concrete's supporting blocks and the appearance of numerous cracks over 0.5mm.

The formation of a watery slurry following concrete "sweating" at the interface between the first and second concrete layer, from concrete layer cracks and at slab joints was a characteristic of all pilot slab track systems. The sweating has not yet affected traffic safety, but would have impact on the lifecycle of structures.

**Displacement of roadbed layers**

The results of measurements of roadbed layer displacement as performed with a slab track fiber-optic control system [1] are as follows:

Settlements are quite gradual and are not clearly pronounced for the concrete slabs or variable stiffness areas. The settlements varied from 0mm to 2mm.

The settlements under the stabilized soil layer ranged from 0mm to 11mm, while two pilot tracks reported settlements of about 2mm. The two remaining tracks had settlements ranging from 7mm to 11mm. The maximum settlements do not correlate with the slab boundaries. The largest displacements were registered during ground thawing in spring.

## Maintenance labor costs

The cost of maintenance labor for the four slab track structures was roughly the same.

The most troubled area for all pilot track sections (Tines, Alstom, MaxBögl, and LVT) was at the transition zones between slab track and ballasted track. Settlements in these areas could reach as much as 40mm and were corrected at regular intervals through spot tamping. The worst track condition with the largest settlements and wearing of crushed stone was registered at the first transition section of LVT, where the metal variable section bracket was placed in ballast. Five of the 13 sleepers' lower section, which rest on special steel bracket plates required replacement following rapid deterioration. Crushed stone was also replaced in this area.

The smallest settlements were present in the second transition section of LVT that had rubber-coated sleeper soles.

The following repair work was performed during the pilot track operation:

**LVT:** Sealing of numerous cracks in concrete layer, and replacement of 64 of 300 blocks with Schwihag fastening, five of 13 sleepers, and crushed stone in the first transition section.

**MaxBögl:** Sealing of the longitudinal joint and asphalt covering in the inter-track space, replacement of three broken clips, and a single angled guide plate on the slab.

**Alstom:** Replacement of 16 anchor bolts for additional rails on sleepers located in the transition area sleepers, as well as all 50 fastenings of additional rails on the baseplate.

**Tines:** Eliminate track pumping by sealing the concrete slab joint and poor concrete layer, additional leveling with adjusting shims in W30 fastening (13).

The total working hours spent on maintaining the slab track systems during trial operation before reaching 600 million tons of carried gross weight were as follows:

**Tines:** 279.5 man-hours; 15.5 machine-hours;

**Alstom:** 180.5 man-hours; 6.5 machine-hours;

**MaxBögl:** 112.5 man-hours; 9 machine-hours;

**LVT:** 210 man-hours; 16.5 machine-hours.

MaxBögl's system required the least number of man hours for slab track maintenance, which was due to the fact that concrete track slabs were prefabricated. Moreover, it is the only pilot structure that coated the intertrack with asphalt in order to minimize the ingress of rain and meltwater.

## Comparative estimation of pilot slab track systems

All four pilot slab track systems were deemed to have successfully passed the trial and met traffic safety regulations.

A comparative evaluation of the four ballastless track systems, which rated their varying parameters, and based on expert opinion No 16 of May 27 2016 (the MoM validated on 23 June 2016 by Valentin Gapanovich, senior vice-President of Russian Railways (RZD)) rated the four trial slab track systems as follows: 1st: MaxBögl; 2nd: Alstom; 3rd: LVT; 4th: Tines. It is worth pointing out that the evaluation is conditional and depends significantly on the team of experts that selected the weighting coefficients. In addition, the evaluation did not include the construction cost of the pilot slab track systems under comparison [2].

The final decision between which slab track system to use for a specific project should be made on the basis of life cycle cost [3] which is adjusted for relevant discount factors.

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# New service agreements enhance locomotive service and repair efficiency

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Following reforms introduced on July 1 2014, most maintenance and repair (MROs) of Russian locomotives was transferred to independent service companies. Almost 15,000 of Russian Railways' (RZD) locomotives, or more than 70% of the TPS fleet, are now serviced and repaired under a 40-year contract with enterprises which are part of Locomotive Technologies (LokoTech), with the service companies' revenue depending on the locomotives performance. [1]. Indeed, the absence of a budget payment for conducting MROs fundamentally alters the motivation of service companies in comparison with the directorate when conducting locomotive repairs. Simultaneously, locomotive usage intensity increases due to a reduction in idle time when units are waiting for maintenance. An enhanced understanding of performance also contributes to an increase in intervals between overhauls and the extent of locomotive operation in certain regions. Experience has shown that increasing TRS reliability and the efficiency of operation while incorporating new developments in information technology that benefit the maintenance and repair system is only possible when switching to these kinds of service relationships.

## Advantages of outsourcing MRO

The experience of the first few years of operation at TMH-Service and the group of companies which make up Locomotive Technologies (LokoTech) confirms that the decision to transition to the maintenance service system for MRO was correct. Since the first service was outsourced in 2012, when TMH-Service commenced a five-year service contract for 5,046 RZD locomotives, total locomotive productivity has increased by 15%, while the cost of maintenance per kilometer has decreased by 19%. In addition, the number of unscheduled repairs and consumption of spare parts has been reduced, while MRO on the whole has been cut.

In 2016, the number of technical failures reported to TMH-Service from locomotives that have operated over 1 million km was reduced by 12.9%. Zheldorremmash also reported a similar 13.6% decline. The total idle time at depots for electric locomotives fell by 51.2% compared with 2015, while diesel locomotives fell by 31.3%.

Zheldorremmash repaired 2451 locomotive units in 2016, while TMH-Service's various divisions fulfilled the remainder of the program. Over this period TMH-Service subsidiary companies completed the production program as follows: 55,477 diesel locomotive sections were repaired, which was 99.2% of the anticipated program, while similar repairs were carried out on 52,619 electric locomotive sections, or 101% of the expected level. Similarly, targets for maintenance of diesel locomotive equipment at TMH-Service depots was surpassed by 2% with 41,832 items completed, while 31,654 items of electric locomotive equipment were also maintained, 1% more than expected.

The article describes the major areas and priorities for further improving the efficiency of MRO – namely the creation and introduction of information control systems in service locomotive depots with the goal of improving the efficiency of the MRO process.

## Increasing the efficiency of service maintenance

TMH-Service is the largest service company in Russia. It has a portfolio of more than 90 locomotive depots (SLD), while the company itself belongs to a group of assets under the management of Locomotive Technologies (LokoTech), which holds Zheldorremmash, Trading House TMHS, and a number of other organizations.

RZD's objective of outsourcing maintenance to service companies, which is outlined in agreements 284 and 285 from April 30 2014, is to increase the reliability of its locomotive fleet. [1, 2] In this case, the main control indicator is the coefficient showing the technical readiness of locomotives [2], defined as the ratio of the useful work of the locomotive and the total time in service:

$CTR_{Nb} = T_{pcn} / (T_{pcn} + T_{otn} + T_{pln} + T_{aus})$, where

$T_{pcn}$ – stay locomotive in working condition;

$T_{otn}$ – stay locomotive inoperable due to warranty repairs;

$T_{pln}$ – stay locomotive inoperable due to maintenance;

$T_{aus}$ – total waiting time service and other administrative costs.

In 2016, LokoTech managed to increase CTR more than planned – from 87%, as outlined in the agreement with RZD, to 89%. However, as analysis of the process shows [2] (fig. 1), CTR is not so much dependent on the reliability of individual locomotives but on time lost due to the logistics process. Indeed, more than 40% of CTR is associated with idle locomotives waiting for repair. Thus, improving the logistics of SLD, and managing production processes is critical to improving the maintenance system and increasing locomotive reliability.

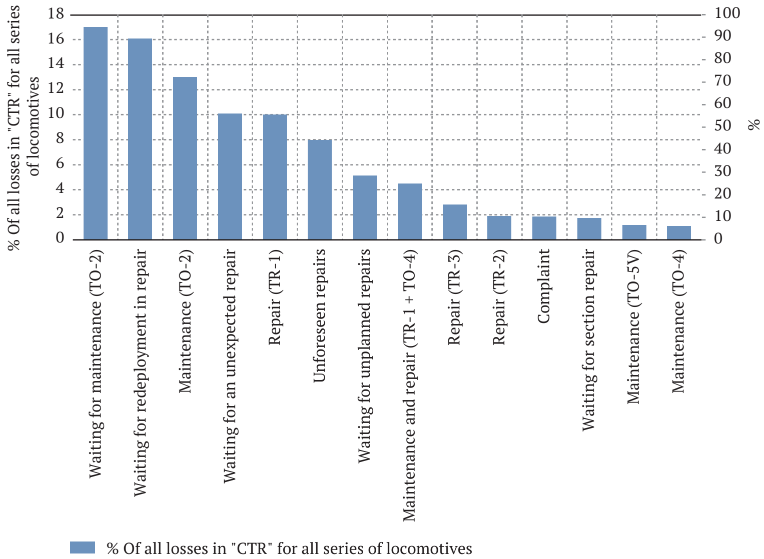


**Fig. 1.** The Pareto Chart showing CTR loss

## Automated maintenance management

One of the important areas for increasing the efficiency of locomotive MRO is the introduction of information management systems [3].

At TMH-Service, in the framework of improving the management system for the maintenance of locomotives, work is underway to create and implement a single information system for typical managerial processes, such as bookkeeping, trade, personnel, salaries, and warehouse management [4]. On the basis of this standard system – 1C ERP – it is proposed to create a subsystem for managing MRO production processes, which is known as the ACS Network Diagram (ACS SG).

ACS SG automates management of the technical processes used in maintenance and repair of locomotives, and is not found in any standard information system. MRO processes at service locomotive depots are complex and generally encompass the following tasks (fig. 2):

– monitoring of operation and technical condition of locomotives (block 1);
– formation of schedules of setting locomotives for repairs (block 2);
– in-house planning (runway) (block 3); and
– management of production processes, including material and production support for repairs and elements of the quality system (block 4).

All processes undergo complex factor analysis (block 5) according to the principle of continuous improvement (the PDCA cycle) with the adoption of corrective measures.

ACS SG is the basis of the locomotive lifecycle management system, and has been created jointly by Transmashholding and Lo-

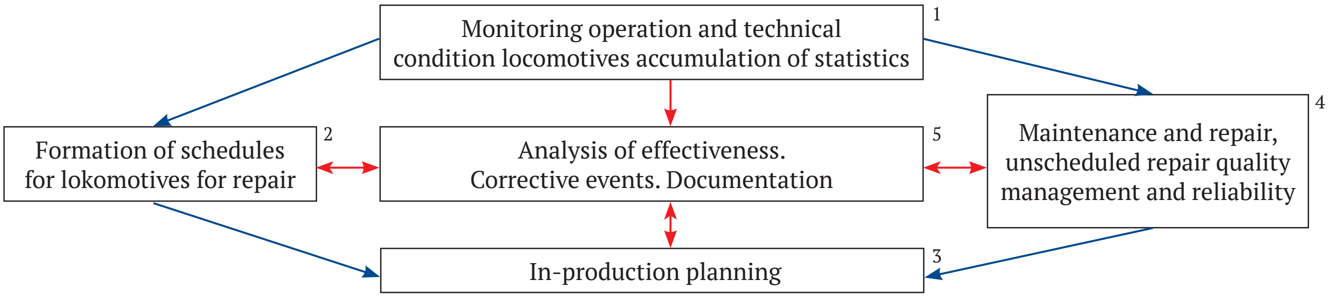


**Fig. 2.** The main functional tasks of the ACS Network Diagram

coTech. The SG's automated control system facilitates the switch to servicing locomotives using new technologies and is based on a life cycle contract (LCC).

The structure of the ACS Network Diagram processes (Figure 3) corresponds with the structure of the tasks outlined in Figure 2. During locomotive operation, performance is monitored according to data from the automated operational system (block 1.1), with technical condition and operating modes monitored by the onboard data microprocessor control systems (MCS) (block 1.2). Simultaneously, this monitoring data can forecast the types of repair that a specific locomotive will require at seven-year, annual, and quarterly intervals. Planning for seven years ahead (block 2.1) is necessary to assist maintenance facilities and depots to plan what equipment they will require (block 3.1) as well as the logistics of managing these maintenance operations (block 3.2). Planning for the year ahead (block 2.2) is necessary to inform logistical support (block 3.3), as well as SLD and the factory resources (blocks 3.4-3.5).

Monitoring data from the operation of locomotives as well as the technical condition and operating modes (blocks 1.1 and 1.2), together with the data from depot technical diagnostic systems (block 1.3), are used alongside other planning modes, including operational three-day and even a decade plan (block 2.3). On the basis of this operational planning, locomotives are put up for repairs (block 2.4) and/or maintenance. At the same time, operational resource planning takes place: logistics (block 3.6) and production preparation (block 3.7). Repair planning takes into account the actual technical condition, which will enable preventative maintenance and repairs to take place according to the actual condition of a specific unit.

If a locomotive fails during service, it is sent for unplanned repairs (block 2.7), which are also planned (block 2.3). Once the locomotive is received (block 2.4) and the actual repair, based on the SLD, takes place (block 2.5), it is optimised in order to eliminate the detected failure.

Both planned and unplanned maintenance is carried out according to production load planning (block 4.1), labor resources (block 4.2), logistics MRO (block 4.3) and the issuing of repair kits in the shops (block 4.4).

The final stage is the delivery of the locomotive to the customer (block 2.6), which includes registration of all managing and accounting documents. In parallel to the PDCA cycle, quality management and existing problems are eliminated (block 1.4).

All the processes of managing the locomotive MRO lifecycle are considered as an integral part of LokoTech's general management, or ERP-system, which has been created on the basis of the 1C software package.

Automated management of all information sources regarding the lifecycle of each locomotive is saved in the ACS SG database. This not only manages the technical condition of locomotives, but also increases the efficiency of service maintenance and locomotive engineering in general.

## Built-in quality

For locomotive depot employees, the ACS Network Diagram is accessible through a user-friendly interface. This information system incorporates mathematical methods, international standards of quality management, reliability and risk management, as well as lean manufacturing.

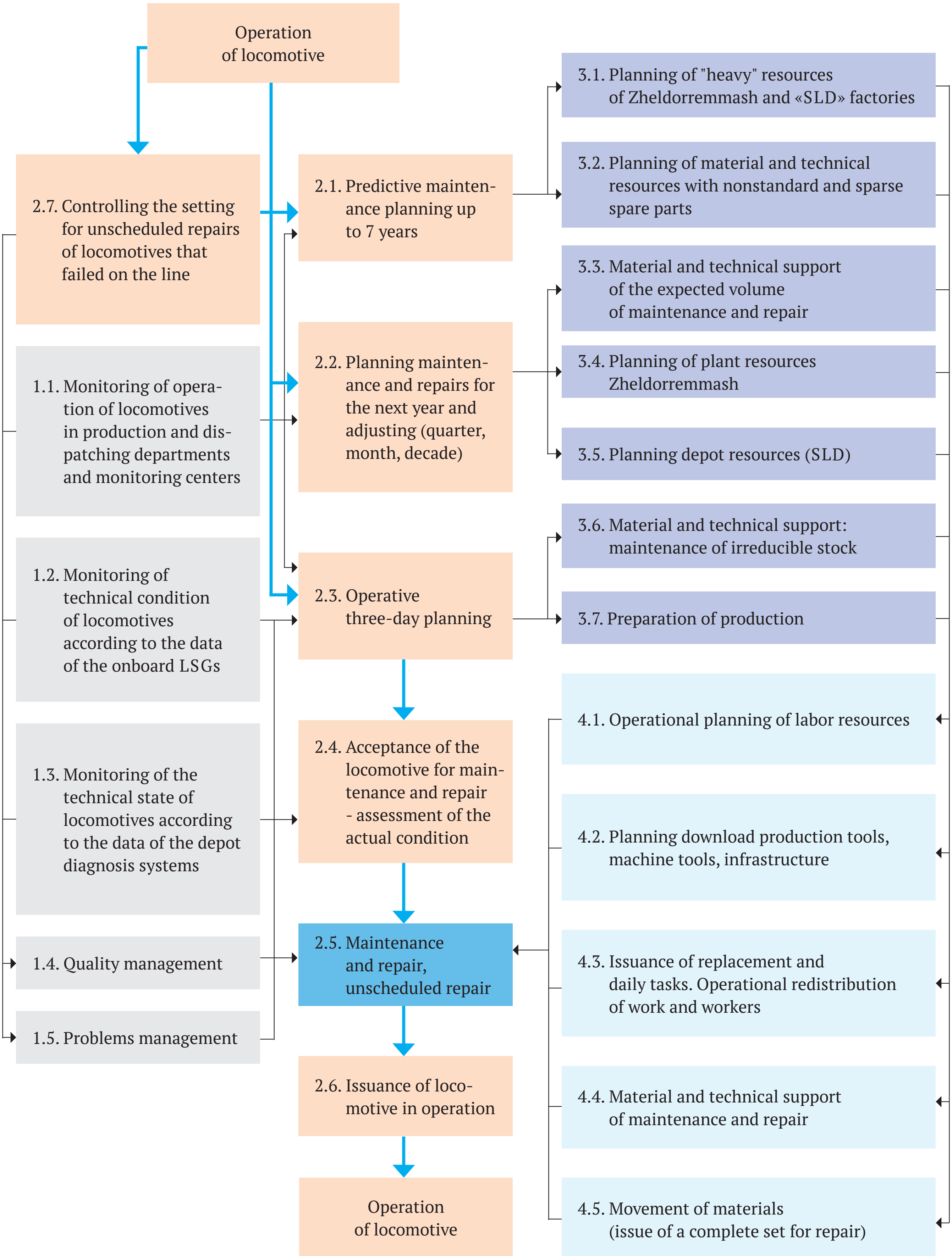


**Fig. 3.** Basic blocks of the ACS Network Diagram

Analysis of work conducted over the last 80 years to improve the production process management system and the reliability of products shows that a number of international (ISO), Russian (GOST) and corporate standards have emerged which contain methods, techniques and control algorithms, including statistical management methods. [5] The application of ISO, GOST and STK makes it possible to significantly improve the efficiency of MRO in SAL. However, application is generally hampered by the insufficient skill level of employees and the prevalence of the established repair practices. The problem is overcome by adopting a methodical practice which emphasises "built-in quality," and encapsulates algorithms and mathematical calculations approved in the SLD's information control system. Encapsulation along with polymorphism and heredity are inherent properties of modern object-oriented programming, where complex calculations are included in the object, and the interface of the object makes it easy to use the results of these calculations. For example, a user working in MS Excel can sort data with a single keystroke, with the built-in sheets invoking the encapsulated sort procedure without the user know which sorting principle is applied.

When implementing the ACS control system project, it should encapsulate mathematical methods into the following processes [4, 5, 6]:

– forecast the locomotive setting for MRO through modeling on the basis of calculating mathematical expectations and the standard deviation of the mean daily operation of locomotives and idle times at the depot;
– a decision support system to facilitate the process of transitioning from comments on the locomotive (diagnostic map) to additional supercyclical works using probabilistic approaches, fuzzy sets theory, and neural networks;
– reduction of inventory due to the application of algorithms for planning and allocating spare parts and materials, including using the mathematical apparatus of queuing theory, network planning, and statistical and factor analysis methods, and
– control of MRO efficiency by using statistical and factor analysis methods, graph theory, and Gantt charts.

The ACS Network Diagram interface is presented to users in windows, hidden behind which are the actions encapsulating control methods, algorithms and mathematical formulas primarily relating to statistical management methods.

Next, we consider an example of encapsulating mathematical and statistical control methods in the automated control system for the SG. [6]

Supplying the production process with necessary resources is the basis of sustainable production. An important feature of MRO under SLD conditions is the improved ability to predict the need for certain spare parts and commodities.

When carrying out maintenance and repair for TO-2 (with a duration of 1.5 hours), TO-3 (12-18 hours) and TR-1 (18-36 hours), the probability of additional demand is very high. This may lead to a shortage of spare parts in the warehouse, which in turn could lead to locomotives becoming idle in the depot. As a result, it is very important to learn how to manage the minimum level of supply in the warehouse. Following the recommendations of consulting companies, LokoTech proposed using the known formula [5] which is based on statistics regarding consumption and receipt of certain commodities. Knowing the average consumption of parts makes it possible to forecast demand and, accordingly, the irreducible stock as the square root of the sum of the overlaps the deviation of the working cycle and the deviation of consumption:

$$Q = Z \times \left(\sqrt{(\sigma_R^2 \times M^2) + (\frac{R \times \sigma_R^2}{T})}\right),$$

where $Q$ – amount required for a minimum margin (pieces, kg, etc...);

$M$ – expectation needs of daily goods and materials (pieces, kg, etc...):

$$M = \frac{\sum_{i=1}^{max} x_i}{max},$$

where $x_i$ – flow details for the i-th day;

$max$ – the number of cases, days;

$\sigma_M$ – standard deviation (SD) average requirements $M$:

$$\sigma_M = \sqrt{\frac{\sum_{i=1}^{max} (x_i - MM)^2}{max}},$$

where $MM = 30 * M$ – expected consumption for the month;

*R* – the expectation of rate of delivery of goods and materials (days):

$$R = \frac{\sum_{j=1}^{mx} y_j}{max},$$

where $y_j$ – j-th time of delivery;

*mx* – the number of shipments of observations (number of parishes);

$\sigma_R$ – SD R;

$$\sigma_M = \sqrt{\frac{\sum_{j=1}^{mx} (y_j - R)^2}{mx}},$$

where *T* – the number of days in the period of calculation;

Z – level of service (in standard deviation units) depending on a given probability of possessing parts. For example, if the probability of having parts in the warehouse is 95%, then Z is assumed to be 1.64. The following is the tabular data used in the calculations:

95% $Z = 1.64$;
97% $Z = 1.88$;
99% $Z = 2.33$;
99.7% $Z = 2.75$;
99.99% $Z = 3.72$.

We propose replacing the deviation of delivery (R) in the formula under consideration with the time of delivery of the part from the buffer store, which is more in line with the technology of operating SLD because deliveries are not strictly periodic. In addition, as they are from manufacturers' factories and could be delivered in a period of up to one year, this negates the effectiveness of the formula. TMH-Service took measures to create buffer stores – one per each region. In this case, the delivery time is reduced to less than a month with a fairly small SD, which makes it possible to effectively use the formula.

Let's consider an example. Let's say that on one day the depot consumed 100 fuel filters (*M*). At the same time, the average monthly SD of filter consumption will be 200.

Delivery to buffer stock takes 10 days (*R*) so at RMS $\sigma_R = 2$ days. Then, with a weekly control of the irreducible stock and a given probability of having a filter 99% availability, we find that the non-reducible stock should be:

$Q = 1.64 \times \sqrt{(2^2 \times 100^2 + (10 \times 200^2)/7)} =$
$= 511$ filters

Other examples of calculations are shown in Table 1. Thus, within the framework of the newly developed ACS system, it is possible to implement a self-learning system for calculating the irreducible margin for each type of inventory. During the repair process, the master orders the correct number of the required parts from the warehouse. As a result, warehouse stock is maintained automatically by calculating and forming an application for a buffer regional warehouse.

This example shows that the proposed formula offers a good result. It should be noted that the shown formula is a top of the pyramid calculation, where the first accumulated statistics xi, then m is calculated expectations and their standard deviations σM. Only then calculations on the basic formula are made. And with this whole rather complicated process encapsulated in the ACS of the SG, it does not require users to have a thorough knowledge of the probabilistic statistical methods of management.

The example clearly shows how it is possible to implement effective MRO management using modern mathematical and logical management methods based on the principle of "built-in quality," which encapsulates management methods in information systems.

**Table. 1.** Sample calculation of minimum reserve

| Parameter | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 |
|---|---|---|---|---|---|
| $Z$ | 1.64 | 1.64 | 1.64 | 1.64 | 1.64 |
| $\sigma_R$ | 2 | 2 | 2 | 10 | 0 |
| $M$ | 100 | 100 | 150 | 50 | 1 |
| $\sigma_M$ | 200 | 400 | 200 | 200 | 0 |
| $R$ | 10 | 10 | 10 | 200 | 30 |
| $T$ | 30 | 60 | 30 | 30 | 30 |
| $Q$ | 379 | 423 | 527 | 1,179 | 0 |

## The automated control system and introducing the Network Diagram

Introduction of ACS SG began in 2016 with specially selected pilot SLDs at Tyumen, Yugra (Surgut), Amurskoye (Komsomolsk-on-Amur), Tynda-Severnaya (Tynda), Bogotol-Sibirskiy (Bogotol), Barabinsk, and Dal'nevostochnoye (Khabarovsk). In 2017, the plan is to expand the pilot project to the entire East region, which encompasses services from Mariinsk, Mezhdurechenskaya, Vladivostok and Nakhodka, on the Bakur-Amur Mainline from Taksim station to Sovetskaya Gavan, and on the West-Siberian region.

TU-28E was the first module introduced to automate the registration of all works carried out in the workshop, with automatic data transfer to the labor and wages departments (OTiZ) for calculation (1C ZiUP module). Deploying this module and information system led to the development of a new ideology of interaction between workers and craftsmen in the workshop. The second phase of the introducing ACS SG is the accounting module M11E, which automatically dispenses materials from the warehouse to the shop floor. TU-28E and M11E systems both utilize mathematical statistical control methods, including the minimum margin commodity-material values control method described above. The remaining SLDs are trained on the basis of experiences and working practices adopted at the pilot depot, with complete implementation of ACS SG at all 92 SLDs planned before the end of the year.

Experience of implementation shows that establishing a transparent remuneration system was received positively by craftsmen and locksmiths. Another outcome that has received positive feedback is the reduction in paperwork. The process does not require manual forms of recording orders, or accumulates limiting list statements and other documents generated in Excel or Word.

Many of the problems that inevitably arise when implementing new technologies are possible to solve online. The main issues that might occur tend to relate to regulations and often are historical in nature. Similar problems were also found when implementing the first information systems at the depot, for example, an integrated driver routing processing system (IOMM later TSOMM), or the workstation for a locomotive crew (APM TCHB). Currently, all locomotive crew management processes are unified, and the same will be done at locomotive service depots.

Another, major issue is bringing workers up to speed with new working practices and, in particular, computer processes. Acquiring the skills to quickly and accurately enter data into ACS SG takes time and also the good will of the employees to engage in the process.

Third, is related to the technical discipline of the depot managers. Working in "fire-fighting" mode does not result in the clear organization of maintenance and repair processes, and as a result, it is difficult to work with ACS SG and assume the principle of "built-in quality" work rather than simply "right" or "wrong" For some leaders it takes more time to learn and master the new way of working than it will their staff.

Fourth, there is no formal description of all processes required for the calculation of the MRO’s complexity and the demand for spare parts. The problem is solved gradually and can develop missing elements.

Fifth, relates to the logistics (MTS) of the process. The system assumes the existence of the necessary spare parts. TMH-Service is gradually solving MTS-related issues, but it does remain a problem. For this and other reasons, the notion of a "workaround" is provided, which will include ITIL service standards.

Sixth: introducing these new systems costs money. While it will deliver benefits in the medium and long-term, there are up-front costs for software, documentation and implementation, the acquisition of IT equipment and suitable internet access.

Seventh, is the need to combat the fear popularized by Edward Deming, namely the requirement for an information-based system to have accurate data and information and a lack of subjectivity. [1] Building information management system involves the accuracy of information, and a lack of subjectivity. Unfortunately, a culture of hiding problems has emerged at many Russian enterprises over a number of decades. To overcome this, enterprises should deploy the principle outlined in the PDCA cycle (Deming cycle), which can re-

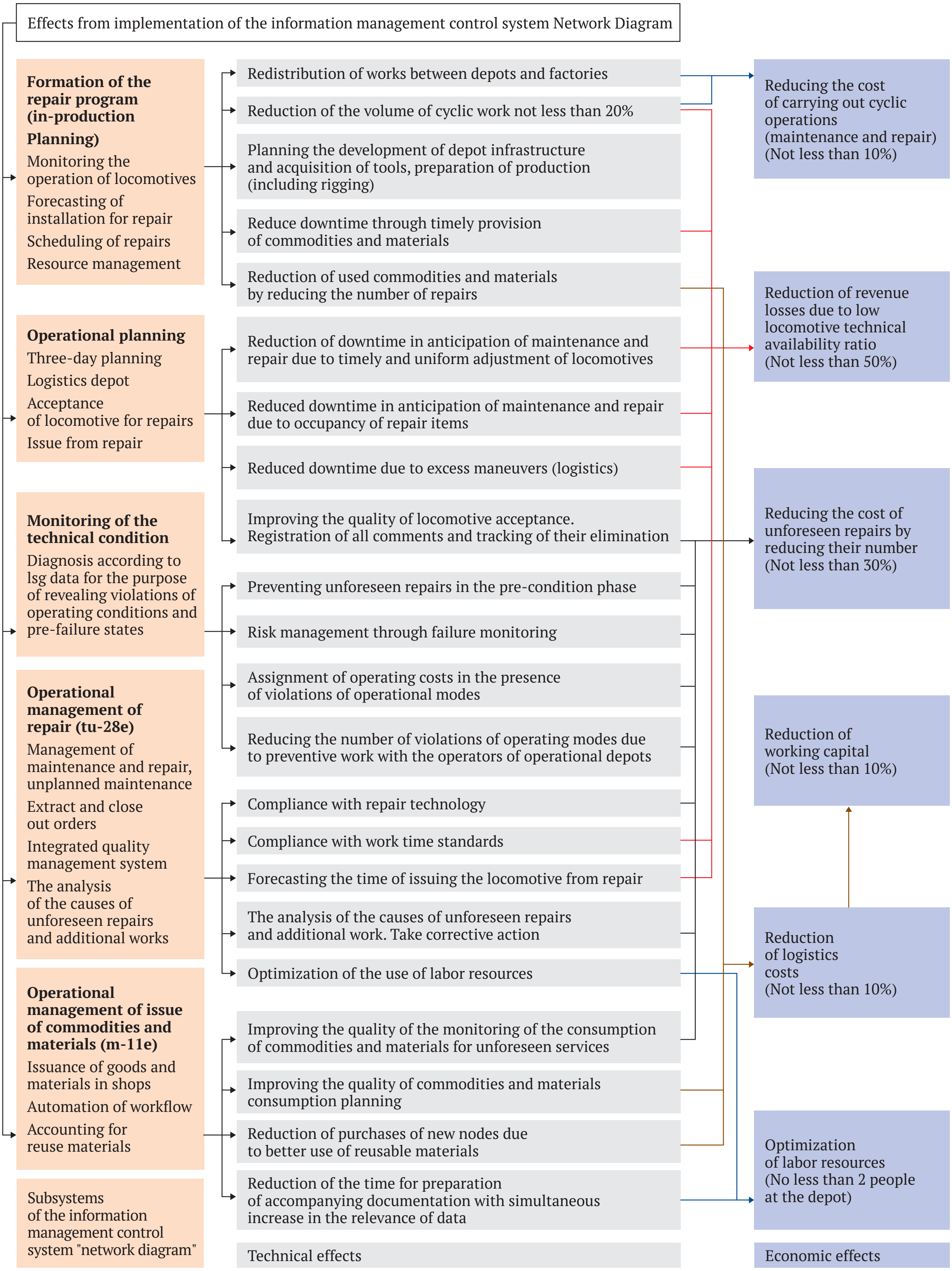


**Fig. 4.** The impact of the introducing the ACS Network Diagram

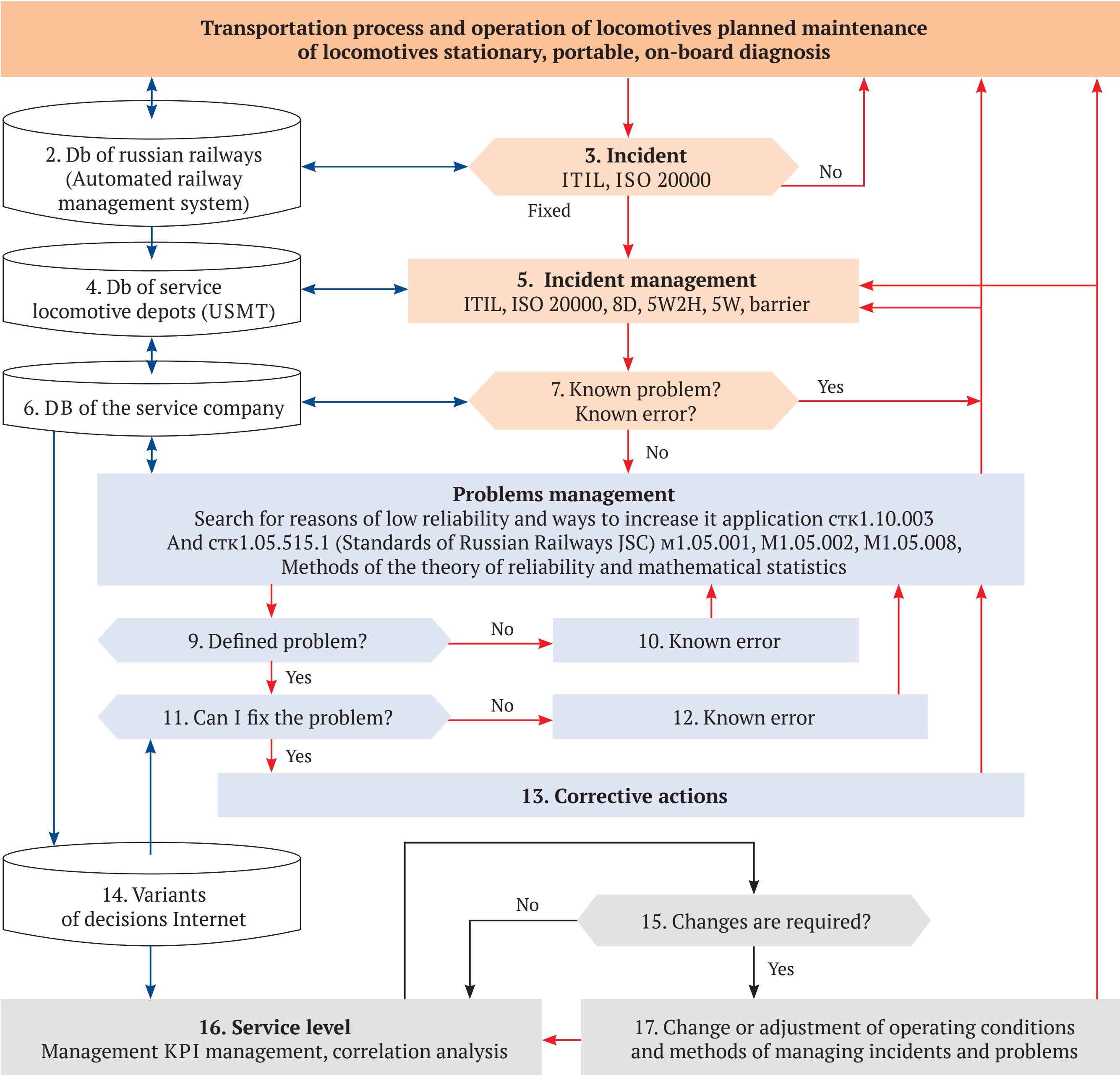


**Fig. 5.** The three-loop model showing the technical condition of the moving element of a locomotive traction control system

cord statistically reliable data on production processes objectively. Unfortunately, this remains quite a complicated and long process.

Despite these issues, there is a strong belief that when the ACS SG is introduced by TMH-Service, it will produce the desired effect.

## The effectiveness of service MRO

Implementing ACS SG does not affect the company's earnings, which according to the contract, or the Service Level Agreement (SLA), is defined by the distance travelled by locomotives when in operation. This is achieved by reducing the losses resulting from poor maintenance planning, penalties resulting from locomotives having a low coefficient of technical readiness (CTR), performing unscheduled and additional work, and carrying out a large amount of manual work such as compiling accounting reports. Other costs include the deficit resulting from a large stock of spare parts. [4].

Introducing ACS SG will not completely eliminate losses, but studies have shown that it can reduce them by at least 30% through reducing maintenance and repair costs (fig. 4).

Thus, the transition to a service MRO system in combination with process automation will significantly increase the efficiency of locomotive maintenance, improve life cycle costs and increase reliability.

In addition, the introduction of an automated control system improves efficiency and the service provider's ability to respond to customers' requests as well as optimize and increase the flexibility of the company's business processes.

## Conclusion

The transition to designated service companies providing MROs for locomotives was a fundamental change. It was prompted by the failure of the budget payment system for MRO to generate the innovative solutions that would improve the efficiency of managing the life cycle of Russian locomotives. One key change that has followed this new policy is the introduction of integrated management information systems which operate on the basis of a principle of "built-in quality" and encapsulate probability and statistical methods of management, as well as international quality management standards.

The new management methods identified a number of control models, many of which are now patented [7, 8, 9]. Figure 5 shows the patented three-contour model of managing the reliability of locomotives which has been implemented by LokoTech.

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# Technical features of Russian high-speed passenger trains

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Russia is expected to start construction of its first dedicated high-speed rail line within the next few years. This new high-speed infrastructure will provide a world-class form of transport, which is important in such a large country with great distances between major cities. The cumulative length of the world's high-speed lines now exceeds 37,000km with the most significant growth, which has doubled the the overall network size, taking place in the last five years.[1]

Russia's first dedicated high-speed link will connect Moscow and Kazan. The 770km line will utilize slab track technology and will be designed for a maximum operating speed of 400 km/h on the line and 350km/h on bridges. Rolling stock will be capable of reaching 400km/h during certification tests and will have a top operating speed of 360km/h.

The technical specification for Russia's very high-speed rolling stock was developed in 2015 and further updated in 2017. The specification follows world best practice for operating very high-speed trains and also incorporates experiences from high-speed operations using Siemens Velaro RUS high-speed trains on the Moscow – St Petersburg line.

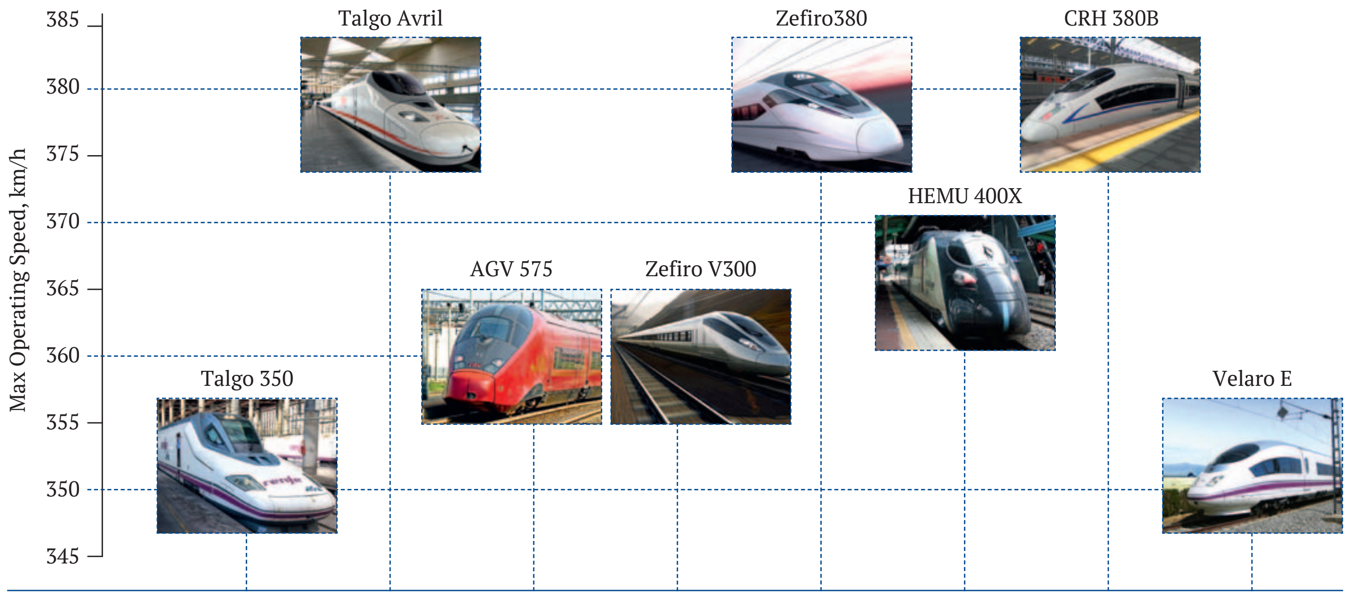
Some global rail vehicle manufacturers are able to offer more than one very high-speed train with a top speed that meets the requirements of Moscow – Kazan line. However, reaching these speeds in varying and often extreme environmental conditions will require an adapted design and technical solutions.

The ability to cope with these environmental conditions – where temperatures can fall anywhere within a 100 °C range, and as low as -48 °C – will dictate which solution is chosen. For example, low temperatures have an adverse effect on metal strength parameters, resulting in the deterioration of the carbody and components.

**There is currently no off-the-shelf very high-speed rolling stock solution that meets the technical specifications required for operation in Russia.**

These types of climatic conditions are regarded as extraordinary in Europe and conventional rail vehicles are designed to operate at no less than -25 °C. For instance, the Siemens Velaro E and Talgo Avril used in Spain operate in temperatures ranging between -20 °C and 50 °C. Moreover, many operators reduce the speed of their high-speed rolling stock in the event of extreme environmental conditions. For example, French National Railways (SNCF) limits the velocity of its high-speed trains to 230km/h following excessive snowfall. Deutsche Bahn in Germany also reduces speeds from 300km/h to 200km/h during periods of snowfall in order to minimize the risk of accidents and damage to rolling stock. Spanish operator Renfe similarly slows down its trains from 300km/h to 230km/h and sometimes to 160km/h depending on weather conditions. The only country where high-speed rolling stock is operated in an environment similar to Russia is China. In particular, the Harbin – Dalian high-speed line, which opened in 2012, crosses an alpine region where temperatures range from -40 °C to 40 °C. For passenger service, the line uses CRH380B rolling stock, which have a top speed of 380km/h. However, due to severe weather conditions and speed limits imposed by the Chinese Ministry of Railways following the Wenzhou train crash in 2011, high-speed rolling

[1] Jan C. Harder. Evolution of HSR railroads in the world. Trends of 2020 through 2030. Railway Equipment Magazine. 5/2016. No 2 (34). p. 28–35.




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Real operating speed, km/h | 330 | *Under certification* | 300 | 300 | 300 | *Under tests* | 300 | 310 |
| Track gauge, mm | 1435 | 1435-1668 | 1435 | 1435 | 1435 | 1435 | 1435 | 1435 |
| Power supply | 25kV AC | 25kV AC | 1.5/3kV DC 15/25kV AC | 1.5/3kV DC 15/25kV AC | 25kV AC | 25kV AC | 25kV AC | 25kV AC |
| Car width, mm | 2,942 | 3,200 | 2,985 | 2,924 | 3,400 | 3,100 | 3,257 | 2,950 |

*Source: IPEM Analysis*

**Fig. 1.** Comparison of current very high-speed rolling stock available from leading global manufacturers

stock has been restricted to operate on the line at a maximum speed of 300km/h under the summer timetable and 200km/h in the winter.

The world's leading manufacturers design and build their very high-speed trains for 1435mm standard gauge, which means that these trains have a smaller profile than those required to meet Russian requirements. According to national standards, the EMU car width in Russia shall not be less than 3.75m, while rolling stock operated elsewhere in the world has loading gauge of less than 3m. Talgo's Avril is the only high-speed train that offers the capability to switch between track gauges, and is successfully proven between 1435mm-gauge and 1668mm-gauge in Spain. But even on its largest model, the car width does not exceed 3.2m. Moreover, the length of Talgo 350 and Talgo Avril cars is 13m and would require dramatic changers to the design of the rolling stock in order to meet the Moscow – Kazan project's requirement to use vehicles that are over 25m long.

Another trend apparent in the world today is the movement to desire the track load. The Moscow – Kazan high-speed line will accommodate a 17-tonne axle load. Yet with the high-speed rolling stock's generous loading gauge as well as the need to operate in extreme climates, it is a major task to develop rolling stock for such a comparatively low axle load and is likely to require the use of composite or light-weight materials for carbodies and onboard equipment, which may impact the cost of the trains.

The project will also require rolling stock to operate on mixed AC and DC infrastructure as the planned route integrates both electrification systems. The Moscow transportation hub uses a DC power supply, while the dedicated high-speed line will have an AC supply to enable operation at 400km/h. Of all existing high-speed train models which could meet the Moscow – Kazan project requirements, only Alstom's AGV 575 and Bombardier's Zefiro V300, both of which are in service in Italy, have a dual voltage system. Despite having a maximum operating speed of 360km/h, the same speed specified for the Moscow – Kazan Line, these Italian trains only operate at a maximum of 300km/h because Italian rail infrastructure is not certified for higher speeds. This example supports the relevance of the decision to add some leeway in the operation speed below the infrastruce's actual capability.

All manufacturers of very high-speed rolling stock which can operate at over 250km/h use

As an alternative to dual voltage rolling stock, infrastructure could incorporate two parallel tracks for DC and AC systems. This setup is used in Berlin and enables parallel running of DC S-Bahn trains and very high-speed trains using AC catenary. However, implementing this solution in Moscow is technically very challenging as it would require the complete replacement of trackside power supply equipment, signaling and communication systems. While the German solution uses different voltages: 15kV AC 16.7 Hz and 750 V DC, in Moscow, where 3kV DC is used, this may cause induction and interference problems between the AC and DC infrastructure.

an AC power supply system. According to rough estimates, installation of equipment for both AC and DC systems will add 10% to the cost of the rolling stock, or about Euros 1-2m per train. However, in Moscow, the costs associated with converting DC power supply to AC significantly outweigh the cost of using a dual voltage system. The complexity of such an exercise is also prohibitive.

Another distinctive feature of the technical specification for the Moscow – Kazan high-speed train is the optional application of an eddy current brake. This brake system is not widely used on high-speed networks around the world, with rare examples including ICE 3 trains operated by DB and some Shinkansen trains operating in Japan, with both having a top speed of 320-330km/h. Tests have shown that eddy current brakes are most efficient on lines with steep gradients and on trains which operate at over 350km/h. Deploying eddy current brakes also comes with an element of risk. Since rails heat up when the eddy current brake is applied, this brake system may cause track destabilization as well as malfunctioning and even failure of signaling equipment. The final decision over whether to use an eddy current brake for Russia's high-speed trains will be made at the design stage.

There is currently no off-the-shelf very high-speed rolling stock solution that meets the technical specifications required for operation in Russia.

## Regulatory environment

There are currently no Russian standards for a complete high-speed railway application. The only regulations available today and applicable to the Moscow – Kazan project are the Special Technical Regulations which only establish requirements for line infrastructure. International experiences of high-speed train design and development have been widely used in preparing the technical specification for the rolling stock. For example, the European Union Technical Specifications for Interoperability (TSIs), lately updated in 2014, have been applied. These TSIs are used today for engineering of rolling stock not only in Europe but also in the United States which, like Russia, does not yet have dedicated high-speed railway infrastructure and also lacks national rules and regulations. Indeed, in 2016 the US Federal Railroad Administration published a Notice of Proposed Rulemaking identifying requirements for very high-speed rolling stock with a top operating speed of more than 350km/h.

**International experiences of high-speed train design and development have been widely used in preparing the technical specification for the rolling stock that will be used for the Russian project.**

Russia’s national standards currently only account for braking distances for speeds below 300km/h and in normal weather conditions with clean and dry rails. As a result, brake and traction stipulations from EU Standards have been used as they specify braking distances in both normal and extreme environmental conditions (see Table 1) as well as wheelset slip and skid protection systems. Lessons learned from operating Velaro D on the Moscow – St Petersburg line will also inform the optimal braking distances for rolling stock using the future Moscow – Kazan line in extreme weather conditions.

A similar strategy of relying on EU standards has been used to define braking coefficient requirements as national standards only specify the coefficient for speeds below 300km/h.

The technical specifications for the Moscow – Kazan rolling stock includes stricter requirements for environmental protection and noise mitigation than EU Standards and

**Table 1.** Local and international service and operation standards

| Operating speed, km/h | Braking Distance, m | | | |
|---|---|---|---|---|
| | Russian National Standard *normal conditions* | Technical parameters of Sapsan on Moscow-St. Petersburg line *extreme conditions* | EU TSIs *normal conditions* | EU TSIs *extreme conditions* |
| 350 | – | – | 5,360 | – |
| 300 | 3,908 | – | 3,650 | 4,690 |
| 250 | 2,606 | 3,130 | 2,430 | 3,130 |
| 200 | 1,668 | 1,940 | 1,500 | 1,940 |
| 160 | 1,157 | 1,454 | – | – |
| 140 | 931 | 1,097 | – | – |

| Braking Distance, m | |
|---|---|
| Specification of Rolling Stock operated on Moscow-Kazan HSR line *normal conditions* | Specification of Rolling Stock operated on Moscow-Kazan HSR line *extreme conditions* |
| 6,140 | 6,820 |
| 3,900 | 4,690 |
| 2,600 | 3,130 |
| 1,670 | 1,940 |
| 1,150 | 1,454 |
| 930 | 1,097 |

*Source: IPEM Analysis*

US regulations. For instance, the maximum noise emmitted by a passing train operating at two-thirds of its maximum operation speed, or around 250km/h, should not exceed 84 dBA. Noise emission limits for speeds beyond this will be specified by the manufacturer. In comparison, the maximum noise value at similar speeds in the EU is 87 dBA according to European TSIs, while US Noise Emission Regulations allow 88 dBA for very high-speed rolling stock.

Finally, the technical specification stipulates that a 12-car trainset is the basic configuration of any high-speed train used on the new line with the potential to add extra cars to form a 16-car set. Other possible train configurations include the operation of eight-car sets in multiple, which is consistent with high-speed operation around the world. These options offer the flexibility to align train length with varying environmental conditions, changes in ridership or line usage intensity.

## Localization

Manufacturing of high-speed rolling stock for the Moscow – Kazan line is expected to take place in Russia. More than 30 12-car trains will be required for the line, and local content is expected to account for 60-80% of the trains' components. However, there are currently not so many examples of high-speed rolling stock localization projects, with China being a leader in this field. For example, in 2009, Bombardier localized manufacturing of almost 100% of the Zefiro380 (CRH380D) in China, while Siemens also localized manufacturing of its Velaro (CRH3) high-speed train. It is worth pointing out that after successful localization projects, China began developing and building its own very high-speed rolling stock. The first certified Chinese high-speed train, CR400AF, was put into operation in 2017.

Thus, industrial localization will help to achieve the goals and objectives set forth in the Russian Transport Machine Building Vision 2030 and ultimately facilitate implementation of the Russian Rolling Stock Export Strategy.

# Technology transfer and developing mechanical engineering in transport

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Technology transfer plays an important role in the global railway industry, particularly in the development of infrastructure and rolling stock. The process has become the primary method of promoting innovation from the development stage to commercialization, and includes various ways of transforming an idea into a commercial product, including transferring patents, developing technical documentation, exchanging scientific results, and creating joint ventures. National railway operators have introduced requirements for localizing commercial products, which have led to the establishment of a large number of local enterprises over the last decade[1]. For example, the national initiative "Make in India" is aiming to accelerate the introduction of innovations in the country's railway industry in order to create jobs while modernizing industrial practices. Adopting this approach will increase the competitiveness of India's railway industry in the world market, and experience has shown that collaboration with global industry leaders can boost investment in a specific country, reducing production costs in the medium-term while developing the national industry in the long-term. The Chinese experience proves the validity of this approach to the extent that it is forcing global companies to change their development strategies. Many are now creating alliances with market rivals which seemed impossible just a few years ago. For example, in 2016, leading consultants presented these conclusions to the CEOs of transport divisions of Siemens and Bombardier.

## Trends in technology transfer

The global railway industry is following trends first noticed in the pharmaceutical and automobile industries in the 1990s. The Chinese initiative to invite manufacturers to the domestic market with the obligation for technology transfer has created a strong and aggressive world player. However, it is not alone in following this strategy, with the likes of Great Britain, Australia, Russia, the Middle East, South Africa, and now India deploying similar policies. Large manufacturers, seeking business in these markets, have created their own local enterprises, but the pressure to transfer technology to domestic companies persists.

Following these trends, the Eurasian Economic Union (EAEU) Member States opted for innovative development of transport mechanical engineering, paying special attention to the process of creating and implementing new technologies.

## The global market for technology transfer

The global market for technology transfer defies explicit definition. The total global market of the railway industry is estimated to be worth €160bn annually with a growth index of 3%. According to our assessment, global investments in transport will increase over the

[1] See "Localisation as a Challenge" by Jan Harder: http://mir-initiative.com

next decade, with the developing world set to invest more proportionally. Creating joint ventures between established and local players rather than long-term investments in research and development centers or collaborative arrangements between industry and universities is the preferred means for stimulating technology transfer. Under this system, the technology transfer market will grow as local enterprises master manufacturing of established technologies.

Technology transfer usually occurs at the point when all related design works are complete and only minor regional changes can be introduced to cater to market conditions. Practical experience shows that projects utilizing technology transfer increase the export potential of enterprises. However, they require the technology transfer process to take place in close cooperation with global players in order to guarantee that suitable knowledge is transferred. As a result, there are two possible scenarios for new technologies to emerge.

Firstly, when possible, by acquiring R&D results during the early stages of an innovative cycle. In this scenario, profit margins could reach levels of up to 70%. However, the investor will bear major risks, as not all ideas will find industrial application. Additional investments might also be necessary which could reach more than 90% of the cost of the result acquired from R&D, which compares with a typical R&D cost of around 5%.

In the second scenario, the profit potential from new innovations falls to up to 20% but there are fewer risks involved. In this situation, a technology is ready and proven in the global market, and has received positive consumer feedback. As a result, this technology can serve as the catalyst for an enterprise to create their own technologies within the national R&D sphere. Many countries, and in particular Germany and Japan, paid significant attention to importing technologies during the 1990s, and today are world leaders in several technical fields.

All this brings to attention the necessity of a comprehensive study of technology transfer and a better understanding of how it might be activated. In a climate of globalization, international transfer of technologies and scientific and technical cooperation are a basic condition for rapid growth of the EAEU states, and is particularly apparent in the transport mechanical engineering sector.

## Transfer of bogie frame technologies for TEP33A locomotives

Practical experience of engineering competences shows that a technology transfer occurs only when the transfer is fixed by a legal agreement between separate legal entities. If the transfer of technologies takes place without the conclusion of such agreement, it is deemed an information transfer. As a result, the innovative process can be divided into several stages (fig. 1).

Molinari Rail has practical experience in technology transfer. For example, we played a role in the project to localize production of the General Electric (GE) PowerHaul series locomotive under a joint project between GE and Tulomsas, which was established following a licensing agreement between the two companies signed in December 2009. Under this agreement, the bogie frame design was developed on the basis of GE specification but was adapted to take into account European norms and requirements. Molinari conducted the finite element analysis of the frame design for the purpose of modeling strength and fatigue characteristics1. The technology transfer was successfully concluded in 2012.

The next step was to develop the collaborative arrangement between Lokomotiv Kurastyry Zauty (LKZ), GE and Molinari, which resulted in

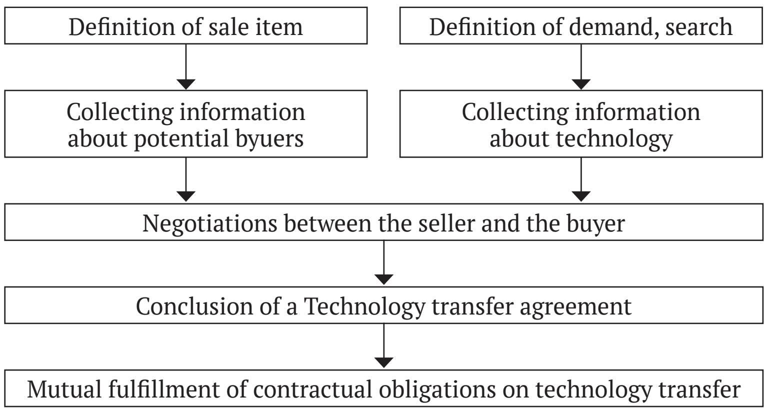



**Fig. 1.** The individual stages of the technology transfer process, from the viewpoint of the seller of technology (left) and the buyer of technology (right)

a new agreement to transfer technology to manufacture the bogie frame for a new passenger locomotive, TEP33A, for LKZ. This was carried out under an agreement between Kazakhstan Temir Zholy (KTZ) and GE, which commenced in September 2012. A subsequent agreement between GE and KTZ to manufacture TEP33As followed a similar agreement signed by the same companies to manufacture TE33A freight locomotives.

The distinctive feature of the new bogie frame design for the TEP33A passenger locomotive is the application of asynchronous traction electric motors in the suspension. This increases the maximum speed of the locomotive from 120km/h to 160km/h, and despite the added design complexity, it offers considerable advantages over axial suspension. For example, fixing a traction motor onto a bogie frame enables it to become completely spring supported and, as a result, less receptive to bumps and vibrations. It also reduces by nearly two-times the unsupported weight, meaning that the wheels and motor block have less impact on the track.

Standard CAD systems are not only a means for developing drawings, 3D models (fig. 2), or for a finite element analysis to idenfity strength and fatigue characteristics, but an important tool for information transfer as CAD standards are used around the world by almost all engineers, designers, and technicians.

The process of technology transfer for the bogie frame was organized in several stages:

- preparation of the specification together with the customer (three months)
- collecting basic data of the technical regulations requirements of the Customs union (three months
- outline design (four months)
- development of working drawings (six months)
- finite element analysis of 3D models (three months)
- preparation of technological documentation (eight months).

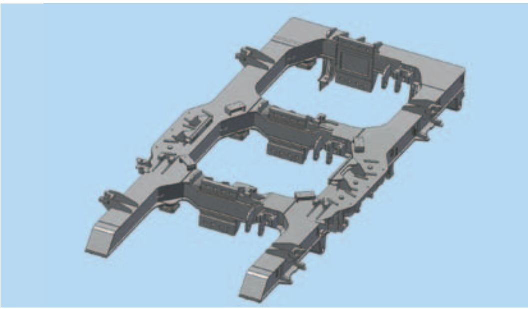


**Fig. 2.** 3D model of a bogie frame (CAD)

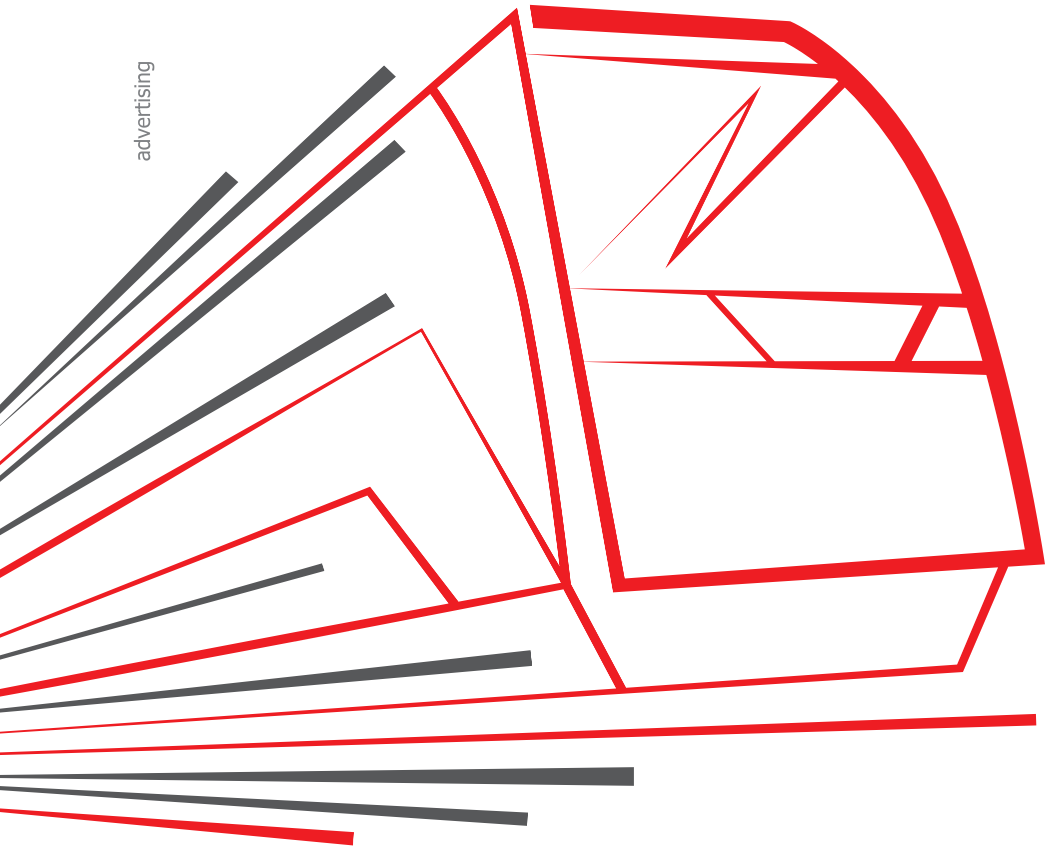
During preparation of the first sample, Molinari engineers, including experts in welding, non-destructive control, cold and hot (ardent) types of reworking steel parts, as well as a process engineer and a project manager, were stationed at the customer's plant.

The transfer resulted in the successful manufacturing of the first sample and acceptance by each party involved in the legal agreement. The complete process – from the order to the end result – took 24 months. This practical application shows the importance of preparing technical documentation with engineers in mind and which offers clear instructions. For example, it could include clear and concise instructions for using tack welds and welded seams, including a plan for non-destructive quality control.

Technology transfer is intended for a specific objective – in this case the bogie frame for the TEP33A locomotive. It is a difficult form of communication to manage as technology in this context is information, and the transfer involves distributing technologies through various information channels – personally, within groups, or within organizations.

Providing an accurate understanding of a technology transfer arrangement offers a general overview of the process, as well as an understanding of the need to conclude a legal agreement in order to protect individual rights. Further research of similar projects executed in the EAEU states will help to create a methodology which can estimate the cost of transferring technology at different stages of the innovation process.

To further the development of transport mechanical engineering in the EAEU states, it is necessary to accelerate the transfer of unique and advanced technologies, and attract financial resources to support innovative activities. Introducing new innovations within enterprises should become systematic. Moreover, during development and commercialization of new products, it is essential to follow the requirements and demands of the market and investors, as well as the purchasers of new developments, technologies, goods, and services.



# ISO Industry Standard for the Rail Sector

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On May 24 2017 the International Organization for Standardization (ISO) published a standard for quality management systems in the rail sector, ISO/TS 22163:2017 “Railway applications – Quality management system – Business management system requirements for rail organizations: ISO 9001:2015 and particular requirements for application in the rail sector”.

ISO series 9000 standards are general standards which may apply to the quality management system of any organization regardless of size or area of activity. But, as the practice shows, every industry has its own industrial standards, which contain specific requirements regarding quality and business management systems.

ISO subsequently published its technical specification ISO/TS 22163 on May 24 2017 while the European Rail Industry Association (UNIFE) published its IRIS Certification™ rules: 2017 on June 1 2017. These generally represent IRIS Certification System rev.03, and are the first industry ISO standards for rail sector enterprises.

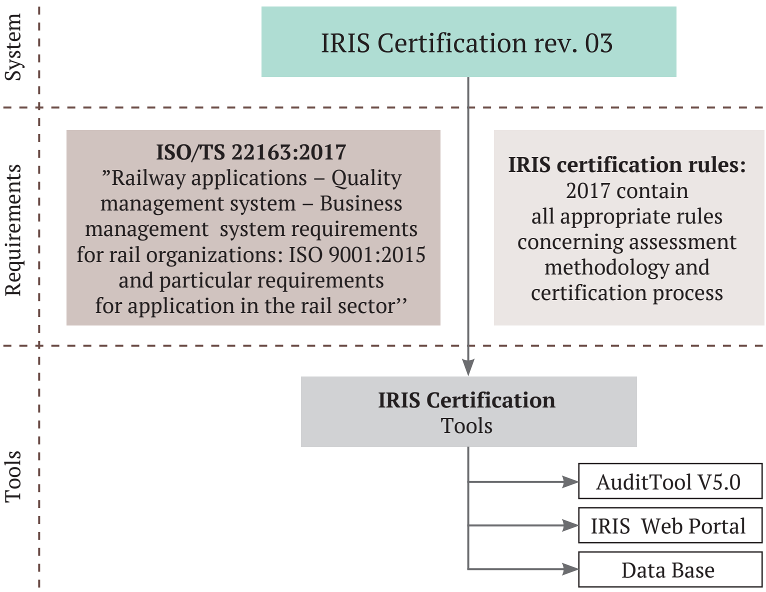


**Fig. 1.** IRIS Certification rev.03

ISO/TS 22163:2017 is a technical specification applicable only for railway industry enterprises. UNIFE and the IRIS Management Center elaborated on the details of the document during the AG15 “Quality management systems for rail sector” working group of the ISO/TC 269 “Railway applications” technical committee. The standard aims to ensure high quality of supplies in the rail industry by creating a global system for assessing suppliers to railway enterprises.

ISO/TS 22163:2017 is based on both ISO 9001:2015 and International Railway Industry Standard (IRIS). The new standard determines basic requirements for railway industry manufacturers in accordance with ISO 9001:2015 as well as specific requirements such as process and project management; supplier development; cost control; life cycle cost (LCC); risk management; reliability, availability, maintainability and safety (RAMS); first article inspection (FAI); and failure mode and effects analysis (FMEA). The standard requires a management system assessment in order to promote continuous improvement, as well as the requirement to develop a complete production chain.

The IRIS Certification rules: 2017 document outlines the assessment methodology and certification process, as well as requirements for auditors and certification bodies.

Major changes in the standard’s requirements are as follows:

– extending the European rail industry quality standards to international markets
– coordination with ISO 9001:2015

– focus on mandatory/recommended processes and key performance indicators
– enhancing process-based management,
– eliminating a risk-based approach, and
– enhancing leadership and management responsibility.

Following suggestions by Russian Railways (RZD), the revision also includes a requirement to analyze the quality of the products in use, with auditors set to receive confirmation of this data from customers actually using specific products.

It is important to note that ISO/TS 22163 is a further step in the development of the IRIS standard. ISO will distribute the new standard, while UNIFE will oversee its critical functions, including monitoring the quality of implementation, offering accreditation to certification bodies, and training auditors under IRIS Certification rules: 2017. The IRIS Web Portal will also remain publicly available, and will reflect all up-to-date information on the certified enterprises.

In Russia, ISO/TS 22163 and IRIS Certification rules: 2017 will be distributed through the federal system of Federal State Unitary Enterprise (FSUE) "StandartInform," which is available in English. A presentation of the official Russian translation of the standard will be made at the Railway Engineering: Future Outlook Congress of international transport and engineering associations set to be held at Expo 1520, the 6th international fair of railway equipment and technologies, in Moscow, on August 31 2017.

Version 02 of the IRIS standard will remain in force until September 14 2018 with the transition to ISO/TS 22163 conducted in parallel. All organizations with current IRIS 02 certificates should complete the transition to the new standard by September 14 2018. All IRIS certificates set to expire after September 14 2018 will become void on that day.

Implementation of the IRIS standard at Russian enterprises conforms with RZD's main policy objectives regarding strategic management of product quality. The railway has already successfully certified key suppliers, with 113 enterprises certified in the Russian Federation between 2010 and 2016. More than a half of these are primary system integrators in the manufacturing of rolling stock and components, with all of the main suppliers of locomotives and rolling stock used on public tracks now certified.

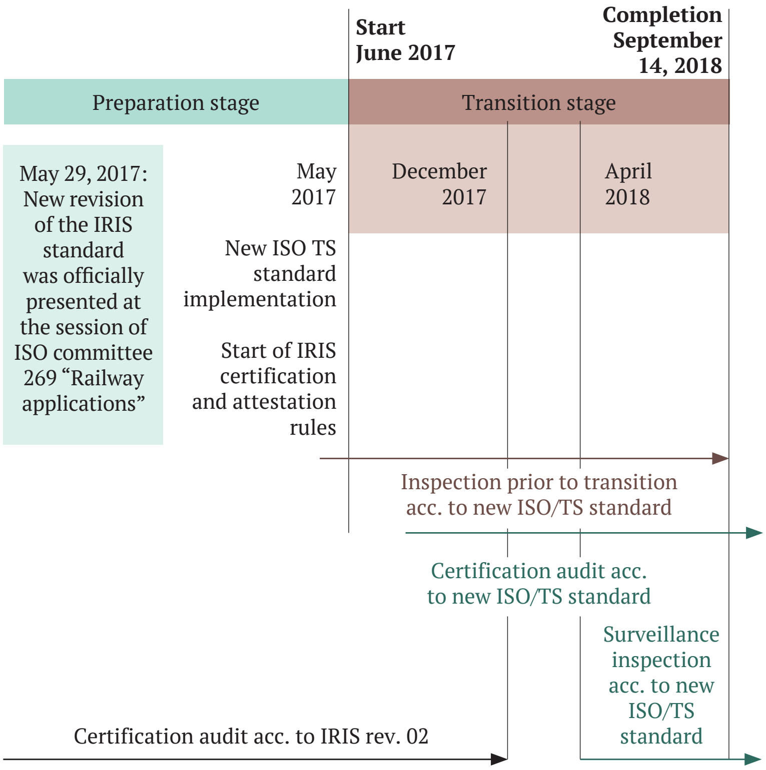


**Fig. 2.** ISO/TS 22163 implementation stages

According to RZD's Quality Management Strategy, certified enterprises active in the rail sector are advised to make preparations to switch to ISO/TS 22163 in 2017-2018 in order to conform with these requirements. They are also encouraged to agree the dates of the transition with the selected certification body. Enterprises which are not yet certified may find it expedient to prepare to follow the requirements of the current version of the IRIS standard as a basis to switch to ISO/TS 22163 during their re-certification audit.

There is a general consensus that implementing BMS in an organization compliant with ISO/TS 22163 will bring a number of benefits:
– optimized manufacturing resulting in fewer defects in final products
– improved market entry due to widespread recognition of the applied standard
– improvements in the company's status, which in turn will enhance its position in the market, and
– reduced costs of obtaining additional certificates, including ISO 9001:2015, AS 9100:2016, IATF 16949:2016.

# The Moscow Central Ring Railway: a railway of innovative solutions

**Efim Rosenberg,**
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During a meeting with Russian president, Vladimir Putin, the president of Russian Railways (RZD), Oleg Belozerov, summarized the preliminary performance of the new Moscow Central Ring Railway (MCR), which entered service on September 10 2016. State-of-the-art technologies, including a new train control system, have been successfully piloted on the line and have proven their worth in difficult and demanding conditions resulting from a tight time schedule. The train control system had already been deployed successfully in Sochi during the Olympics, and in Moscow, the first months of operation were used to test various individual systems in real passenger conditions.

## MCR Trends

The MCR is a unique project that has no equivalent anywhere in the world. It utilizes cutting-edge solutions that enable the operation of commuter trains in a metro mode by introducing traffic control based on moving-block operation. Under conventional fixed-block operation, track is divided into block-sections with traffic lights at their boundaries. The length of these sections is tailored so train braking occurs before an adjacent closed section. As a rule, the length of a block-section is equal to the braking distance of the longest and heaviest train in order to guarantee safety. However, by introducing signaling that uses movable block sections, it is possible to deploy shorter headways between consecutive trains.

The innovative system for train traffic control, which is deployed from ASU-D, a single traffic control center, was initially developed for the Sochi – Adler – Krasnaya

**Fig. 1.** Lastochka EMU (Desiro RUS) running on MCR


**Fig. 2.** Innovative safety equipment in the driver's cab

Polyana line. An update for the system, which was designed to improve reliability, was subsequently developed for the Moscow Central Ring. This adapted system is based on new onboard equipment for rolling stock, as well as upgraded trackside equipment.

For example, the introduction of crypto-protected technology for the electronic transfer of critical data to MCR vehicles (fig. 1) enables EMU trains to operate in Automatic Driver-Automatic Traffic Control mode in line with traffic safety requirements. This system permits automatic traffic management according to a target time-schedule and offers real-time monitoring of trains through the GPS-based positioning system embedded into the onboard safety system (fig. 2). Through data analysis, the system can also identify possible traffic conflicts and apply an alternative time schedule in real-time in order to return to the target schedule.

Similar technologies are already in use in several countries and are designed to overcome issues relating to highly concentrated and mixed traffic flows in suburban areas. These systems appear, on the outside, to represent a sophisticated complex that can be only implemented with due regard to existing economic conditions. Within MCR project, this aspect is evident in the combination of commuter traffic, urban underground and aboveground transport on a single infrastructure system. However, by adopting a single logistics approach to multimodality, which offers improved accessibility to transport services for some capital districts, it is possible to find a workable solution to this situation.

Both the Automatic Driver and Automatic Traffic Control systems rely on a combined spacing control system which deploys movable block-sections and is built on microprocessor-based block signaling. This uses audio frequency track circuits in order to allow mixed traffic operation of passenger and freight trains and offers two modes of operation: traffic light-based signaling for freight trains with agreed weight and length, and traffic light free signaling for rapid suburban service with headways of up to 2min 40s.

To inform the spacing control system, a fibre-optic vibroacoustic object monitoring system, which transmits data digitally, is used. This system can monitor rolling stock passing specific line sections. In addition, deploying the train headway control system on lines with light-to-medium traffic density eliminates the need for trackside signaling, resulting in a significant reduction in life cycle cost. Field testing of this technology has already begun on the Bolshevo – Fryazino section of the Moscow Railway.

With such complex tasks never having been approached before, the advanced technology used at MCR is unparalleled. Digital technologies serve as a basis for the uniform data handling system, and along with train control, the system covers maintenance processes including personnel location.

## Information technology and artificial intelligence

Terms such as Smart Locomotive, Intelligent Rail Station, and Intelligent Rail Terminal have long been on the lips of the scientific society. Now known as the Internet of Things (IoT), these notions imply a quantum jump in IT technology and the introduction of AI-based devices. For railways, the IoT principle relies on adopting routine automation in order to allow sophisticated equipment to perform self-diagnostics, identify process risks and maintain equipment service life. The creation of Intelligent Railway is a worldwide trend, and Russia is among the leading countries developing this concept.

During the opening ceremony of the Moscow Central Ring (fig. 3 and 4), Oleg Belozerov, president of Russian Railways (RZD) assured the country's top leaders that within the next few years trains will no longer require a driver in the cab but will be operated from a central traffic control center overseen by traffic supervisors. This was not wishful thinking. Indeed, the statement reflects the further evolution of a transport systems built on the basis of AI and self-diagnosing systems.

The Intelligent Rail Transport Control System (IRTCS)[1] is one of the key elements of such a system. IRTCS is capable of automatically acquiring all of the essential initial information regarding the status of key processes such as signaling and interlocking systems, rolling stock condition, data on trains speed and weight parameters, positions of locomotives, wagons and trains, and any existing warnings about the network. The system aims to improve the quality of transportation process management with due regard for the complexity of the decision-making process as well as the level of deployed automation. With support from IT infrastructure, IRTCS helps to integrate information-bearing signals, analytical tools and control inputs into a single space where process operations are performed with minimum human intervention.

The MCR also incorporates a function which automates the train speed limiting process. This technology offers interlocking control and provides significant savings in electrical power consumption and maintenance. This is achieved by encoding radio channels by the side of the tracks and replacing the Automatic Train Braking Control System (SAUT) with a wireless system, as well as introducing speed limiting and automatic positioning control operating on track technologies.

Rail infrastructure monitoring and diagnostics is also undergoing fundamental change. A shift to integrating onboard information-measuring systems into rolling stock enables an automatic diagnosis of the condition

**Fig. 3.** MCR opening ceremony


**Fig. 4.** Second circle (MCR) of Moscow Metro

[1] E.N. Rosenberg. Process solutions ensuring better transportation process control efficiency. Railway Equipment Magazine. 2016. No 3 (35). p. 66–72.

Source: Sergey Aldonin (saldonin.ru)

**Fig. 5.** Lastochka EMU on the route of MCR

of a specific piece or section of infrastructure. This development has effectively made rail detection cars, track recording cars, and catenary laboratories redundant. There are also plans to install a rail ultrasonic testing complex onboard an EMU in order to provide reliable operation of automatic train control complex in a heavy traffic environment. The application of these kinds of technologies, which minimize human intervention, enhances railway operation safety due to the significantly lower risk of personnel making decision errors.

As stated by Belozerov, another objective for the future is to replace the train driver with an automatic control system. Driverless solutions are in use on a growing number of metro networks around the world and many of the trains no longer have a driver's cab. Expanding the scope of driverless operation to main line railways has become part of the digital technology implementation strategies adopted by many of the world's leading railways.

The major technical challenge of operating an automated EMU compared with a driverless metro train is the open access to the tracks and the possibility of pedestrians or other obstacles accessing the railway.

State-of-the-art obstacle detection systems like LiDARs radar detection and stereo cameras are proven to offer superior detection than humans. For example, radar detectors are capable of accurately detecting obstacles at night, and in foggy and snowy weather conditions. In addition, the use of these automatic systems is not affected by physical fatigue, or an inability to concentrate and stay alert.

Indeed, the increasing rollout of unmanned and automated processes is having a significant impact on society as many jobs that required monotonous daily operations are gradually disappearing. Instead they are gradually giving way to new occupations, which require greater creativity and high skill sets. This includes engineers responsible for developing and maintaining these new technical systems.

RZD is putting a strong emphasis on developing this area of its operation, particularly in the context of economic, human, and safety aspects. New technologies not only promise to offer improvements in operational efficiency, but will also address the future human resource shortage that will be triggered in the mid-term by the upcoming employment demographic crisis. No less important is an upcoming reduction in labor intensity. Instead, employers will need to provide advanced training for employees so they have the level of knowledge necessary to provide effective action in abnormal situations which require manual control. The new technology deployed on the MCR, including fully automatic trains, is essential to effectively deliver the high volume of passenger traffic using the railway. In addition, according to our estimates, a complete switch to providing infrastructure diagnostics using scheduled traffic should be possible within the next decade.

# How can distributed braking improve freight train performance and reduce delays?

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Enhancing capacity is one of key macroeconomic objectives of current strategies to improve the efficiency of railway transportation in Russia. In particular, Russian Railways (RZD) has emphasized this through recent investments in its infrastructure in the east of Russia in order to facilitate the transport of a higher volume of goods from east to west.

## Background of creating distributed train braking control

In the context of economic growth in China and Japan, the Far-Eastern Rail Division's rail freight turnover has steadily increased in recent years. Managing this increase and the disruptions caused by repair works traditionally performed in the summer season has led to an optimization of the transit process. To improve the Far Eastern Rail Division's capacity, trains now operate on both the Trans-Siberian and Baikal-Amur Mainline. In addition, RZD has focused on developing systems that enable the operation of trains consisting of more than 100 wagons and carrying up to 9,000 tonnes, with the goal of increasing this to 18,000 tonnes in the long-term.

One of the key safety-related parameters critical for operating long trains is the dynamics of both the separate moving units and the train as a whole, especially during deceleration. Employing enhanced dynamic behavior reduces the stress on the rolling stock, minimizing maintenance, increasing a specific wagon's useful life and, as a result, reducing overall transportation costs. The velocity of the brake effort wave is the key parameter affecting this performance.

For many decades, Russian and international companies, and institutes have attempted to create an electropneumatic brake for freight wagons, with several significant breakthroughs reported. However, the costs of these programmes have reached millions of dollars, while the solutions are restricted to all wagons being fitted with electropneumatic brakes.

## Problem definition and solution

In 2011, engineers at MTZ TRANSMASH were instructed to develop a braking system for 1,500-2,000m-long freight trains, which offer similar dynamics and performance to electropneumatic brakes, at the lowest possible cost [1].

In 2012, DTBC.230, (Distributed Train Braking Control System) was successfully tested on the locomotive VL10 No 269, which was fitted with brake valve 230D, and assigned to Moskowka Depot in Omsk. In 2013, the company completed detailed design and preliminary factory validation of train braking distributed control systems DTBC.230, DTBC.130 and DTBC.395, which are compliant with locomotives equipped with any brake controller type, including remote-control brake controllers 230D, 130 and 395.

In 2013, electric locomotives 2ES6 and 2ES10 were fitted with DTBC.130, successfully completing various trials.

In December 2014, a pilot 9,000-ton train ran from Rybnoye to Orekhovo-Zuevo. The train was hauled by main line gas-turbine locomotive GT1h-002 and equipped with DTBC.130, thus proving the system's capability to operate with a gas-turbine locomotive.

In May 2015, after proving its performance, trials of DTBC.130 were initiated with 2ES6 and 2ES10 locomotives used on services between Irtyshskoye and Balezino. The system is still in service, and is used on two to three trains per day.

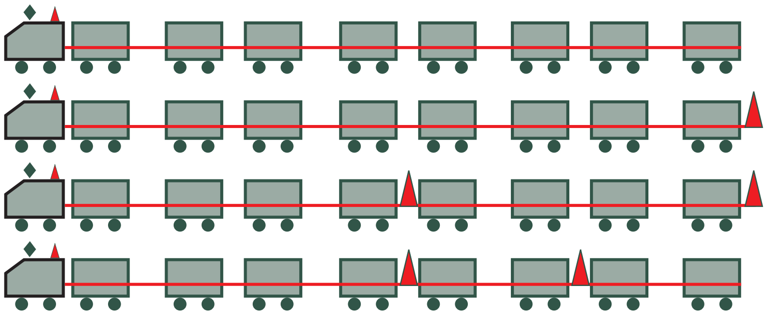


**Fig. 1.** Configurations of RBUs along the train

## Distributed control system for train braking

Heavy freight train configurations that use Rear-car Brake Units (RBU)[1] positioned in various locations (patent RU 144186 U1) are shown in Figure 1:

- no RBUs (braking by locomotive only),
- one RBU installed at the rear of the train (with the brake pipeline discharging at the locomotive and at the rear of the train),
- two RBUs, in the middle and at the rear of the train (with the brake pipeline discharging at the locomotive and at the RBUs locations), and
- three RBUs installed between train cars in locations shown in the below configuration.

It is possible to arrange the RBUs so that the train brake pipeline can discharge at different locations in the train. The locomotive transmits control signals to each or select RBUs in order to allows this discharge to take place.

Teams from MTZ TRANSMASH and MIIT jointly carried out R&D works for three years in order to provide recommendations for the optimal locations and number of RBUs used in a train. The objective was to offer the equivalent braking dynamics to that of a train equipped with an electropneumatic brake, with no impact on the braking behavior of any individual loaded or empty wagon.

The capability for the freight train's brake pipeline to discharge not only at the front of the train as in a traditional configuration, but at other locations, including the rear, is key to this solution.

The resulting equipment package enables brake discharge at any location on the freight train's brake pipeline. However, this approach highlights the problem of identifying the optimal location and number of pipeline discharge points for trains of varying lengths and weights.

This problem was solved by minimizing the maximum longitudinal disturbances which

**Table 1.** Variable parameters

| Car Parameters | |
|---|---|
| Car weight | $M_{car}$ |
| Pressure of brake cylinder, at composite brake blocks | $P_{bc}$ |
| Stroke of brake cylinder rod | $L_{rod}$ |
| **Train Parameters** | |
| Length of train or number of cars | $L_{train}$, $N_{train}$ |
| Train formation options based on car weight | $F_m$ |
| Train formation options based on brake cylinder rod stroke | $F_{Lrod}$ |
| **Brake pipe discharge patterns** | |
| Number of discharge points | $k_p$ |
| Distance between discharge points | $l_p$ |
| Discharge points arrangement patterns | $P_{att}$ |

[1] Rear-car Brake Unit (RBU) is controlled by the locomotive using radio-communication. It discharges at the point of installation in the train and the connection to the brake pipeline.

occur during braking. The inequality of braking effort along the train, found in the specific braking forces of the individual wagons, is the source of the disturbances. It was clear that if the actual braking forces of cars were equal, the force-related disturbances in wagon couplings were zero.

Table 1 shows the parameters identified as variables when looking for a solution to minimize efforts caused by braking.

The variation was reported with regard to the existence or nonexistence of interrelations.

The factors taken into account when calculating the algorithm to obtain the minimum value of the maximum brake forces were:

1. The actual specific braking force of a wagon as determined at a given point in time in view of brake action travel time and brake cylinder working phase – $b_j$, where *j* designates the sequence number of a wagon in a train. In cases where the brake block is not applied to the wheel then $b_j = 0$.
   The obtained values serve as a basis for the array *b*(*1,N*), where *N* is a number of cars in the train.
2. For the same point in time, maximum and minimum actual specific brake force $b_{max}$; $b_{min}$ of the train were identified in the specified value array *b(1,N)*.
3. For the same point in time, the difference between the obtained maximum and minimum values of modular brake force in the train was calculated as $\Delta b = b_{max} - b_{min}$.
   On the basis of $\Delta b$ values as defined for the braking time, array $\Delta b(1,i)$ was defined, where *i* is an index reflecting the braking process completion time.
4. For the value array $\Delta b(1,i)$, maximum value max $(\Delta b)T$ was calculated for the braking time, where *T* is index reflecting the braking time range for the train under consideration.
5. Resulting max $(\Delta b)_T$ was further analyzed by assessing the effect of train parameters, number of discharge points, distances between the points and their location patterns in order to justify the rational distributed discharge of brake pipeline and to minimize obtained maximum values – *min (max* $(\Delta b)_T$*)*.
   In general, the result is:

$$min(max\,(\Delta b)_T) = f(M_{car}, P_{bc}, L_{rod}, L_{train}, F_m, F_{Lrod}, k_p, l_p, P_{att}).$$

In order to determine the actual specific braking force of a wagon after a brake block is applied to the wheel, a known brake force calculation formula was used [2, 3]:

$$b_j = \frac{\sum_{k=1}^{m} (\varphi K(k) \times K_{ac(k)})}{M_j},$$

where $b_j$ is specific braking force of the car;

$\varphi K(2k)$ is coefficient of friction between k-th brake block and the wheel, which depends on velocity and actual application effort;

$M_j$ – car mass based on net weight and load;

*m* – number of brake blocks in a car braking system;

$K_{ac(k)}$ – actual application force of k–th brake block to the wheel, as defined for a given point in time depending on brake cylinder pressure, gear ratio and other values.

In general, the actual application force of the brake block to the wheel for a single-cylinder brake system is defined as:

$$K_{ac} = \frac{1}{1000 \times m}\left(\frac{\pi \times d_{bc}^2}{4} \times P_{bc} \times \eta_{bc} - F_1 - F_2\right) \times n \times \eta_{rig},$$

where *m* is the number of brake blocks per car, affected by one brake cylinder force;

$d_{bc}$ – diameter of brake cylinder piston;

$P_{bc}$ – current pressure of the brake cylinder;

$\eta_{bc}$ – efficiency coefficient of the brake cylinder;

$F_1$ – brake cylinder spring compressive force;

$F_2$ – compressive force of rigging slack adjuster spring reduced to brake cylinder rod;

*n* – gear ratio of brake rigging;

$\eta_{rig}$ – brake rigging efficiency.

The actual brake block-to-wheel force was obtained by observing each of the brake cylinder operational phases:

Phase 1 – filling of brake cylinder clearance space ($K_{ac} = 0$).

Phase 2 – filling during piston movement until the brake block presses the wheel ($K_{ac} = 0$).

Phase 3 – filling of constant volume at pressed brake blocks.

The start of filling process was initiated at the point of brake wave passage initiation, velocity of which is dependent on the air brake control valve parameters. A simulation of the pneumatic portion of the car brake was carried out according to an analysis of the dynamics of the pneumatic drive [4], which is limited by both the constant volume of the supply air reservoir and by the constantly varying volume of the brake cylinder. In addition, the brake cylinder piston has a return spring. The calculations include the mass of the connected rigging parts adjusted to the rod [5]. Volumes are connected through a short branch pipe with cross-section selected with regard to flow losses in the air brake control valve. The calculation model is shown in Figure 2 below.

So, for the above-critical mode

(at $\sigma_{(i-1)} = \frac{P_{BC\,(i-1)}}{P_{RR\,(i-1)}} > 0{,}528$)

current mass flow is equal to:

$$G_i = f\,(\frac{2}{k+1})^{\frac{1}{k-1}}\sqrt{\frac{2gk}{k+1}}\;P_{RR\,(i-1)}\rho_{RR\,(i-1)}\rho_{RR\,(i-1)},$$

where $f$ is effective cross-section area;

$f = \mu f_{out}$;

$\mu$ – flow coefficient;

$f_{out}$ – area of outlet section;

$P_{ER(i-1)}$ – air density.

For subcritical mode

(at $\sigma_{(i-1)} = \frac{P_{BC\,(i-1)}}{P_{RR\,(i-1)}} \leqslant 0{,}528$)

we obtain:

$$G_i = f\sqrt{\frac{2gk}{k-1}}\;P_{RR\,(i-1)}\rho_{RR\,(i-1)}\left[\sigma_{(i-1)}^{2/k} - \sigma_{(i-1)}^{\frac{k+1}{1}}\right],$$

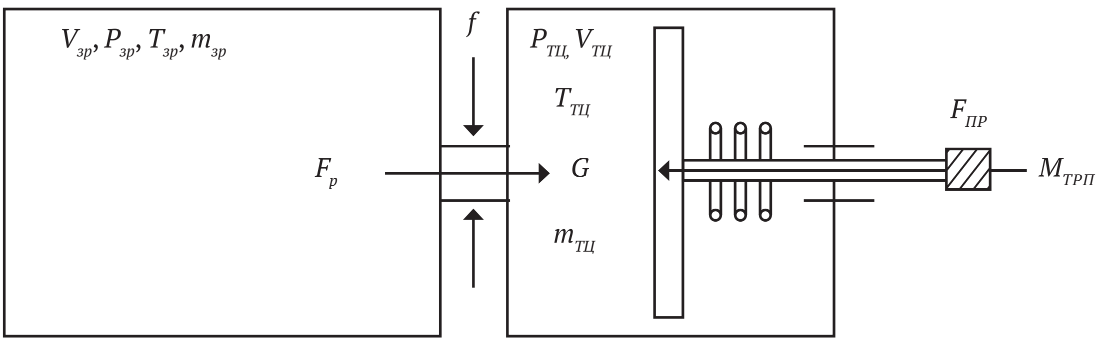
where $k$ is specific heat ratio.

Due to the process of filling the brake cylinder taking a relatively short period of time, the acceleration of the piston motion was taken as uniform at each integration step. Instead the change in adiabatic pressure was used to obtain gas dynamic properties.

Figure 3 shows an example calculation of the brake forces of a 100-wagon train with initial velocity of 100km/h. The train consisted of empty four-axle cars, which were equipped with a conventional braking system, including both pneumatic and mechanical portions, as well as a 14' brake cylinder and 100mm rod stroke. Brake discharge was conducted from the front.

A time-based variation of the irregularity of the specific brake force coefficient is shown in Figure 4. The graph clearly has a maximum, which makes identifying a solution to the problems at hand particularly important.

Varying the length of the train and the number of discharge points requires identifying the optimal discharge location for different train lengths.




$RR$ = supply air reservoir, and $BC$ = brake cylinder;
$P_{ER}$ – pressure in supply air reservoir;
$V_{RR}$ – volume;
$T_{RR}$ – temperature;
$F_P$ – air mass;
$F_{SP}$ – air pressure force to the piston;
$P_{ER}$ – spring pressure force to the piston;
$M_{RIG}$ – mass of rigging elements localized on brake cylinder piston taking into account the piston mass.

**Fig. 2.** Calculation model for brake cylinder filling processes

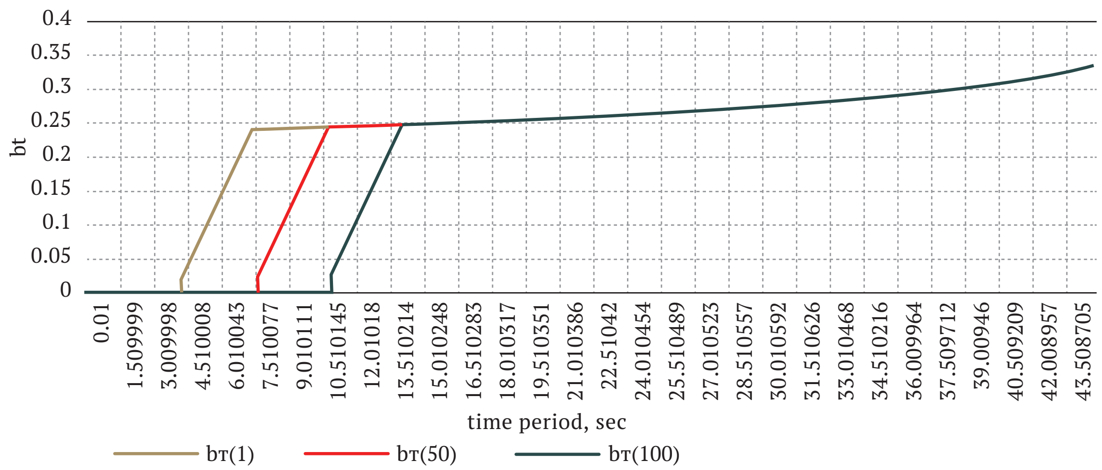



**Fig. 3.** Variation of actual specific brake force during deceleration for 100-wagon train

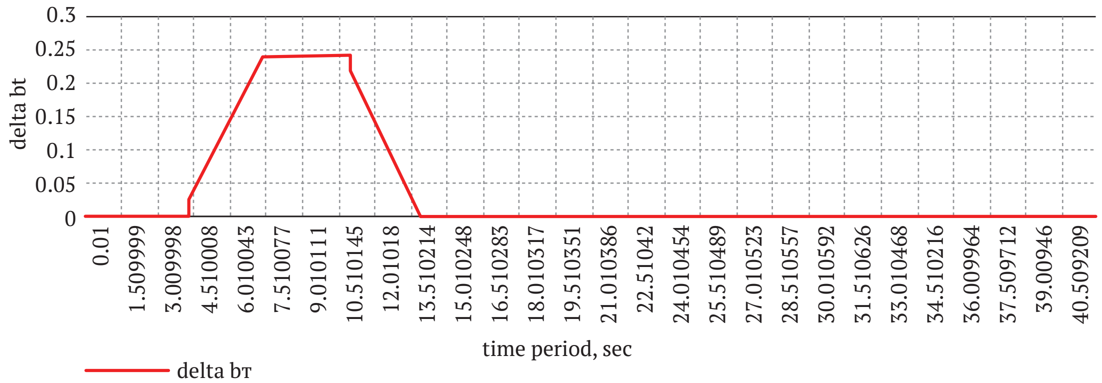



**Fig. 4.** Impact specific brake force irregularity of 100-wagon train on braking time

The following arrangements were analyzed during this process:

– **symmetrical arrangement** (pattern 1), which is characterized by major discharge sources located on the leading (1) and rear (2) wagons (fig. 5).

The underlying characteristic of this arrangement is that additional pipeline discharge points are regularly spaced, and the train length is divided into equal segments;

– **asymmetric arrangement** (pattern 2), which includes a major discharge point in the front (1) of the train (locomotive) and a second discharge installed some distance away from the rear of the train. As a result, the discharge is performed at the front of the train and at a third of the distance of the train from the rear wagon (fig. 6).

The peculiar feature of the second configuration is that the distance from point 1 to point 2 is two-thirds of the length of the train, and from point 2 to the rear end is a third of the length. However, discharge is performed on both sides of points 1 and 2, therefore the distance travelled by the waves from point 1 and from point 2 before they meet is the same meaning that the waves meet at one-third of the distance between points 1 and 2. A wave travelling from point 2 to the rear of the train is also equal to a third of the train length. As a result, in terms


**Fig. 5.** Car discharge symmetrical arrangement (pattern 1)

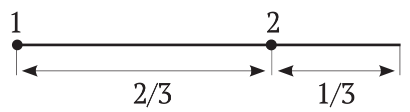



**Fig. 6.** Asymmetric arrangement of train brake discharge for two discharge sources (pattern 2)

[2] Equated length is the length of a train featuring a single-point pipeline discharge arrangement, which is equal to half of the distance between adjacent discharge points allocated along the length of a multiple-point arrangement train.

of the distance that waves travel, the train is divided into equal sections, enabling us to label this condition as having equal wave intervals.

Some modifications have been introduced for the location of second discharge point in pattern 2. The first modification is based on stability of point 2 location, which are equal to a third of train length in case of installation of additional discharge sources.

The second modification involves varying the location of point 2. The first modification reflects the arrangements used in patterns 1 and 2, and it is therefore excluded from consideration.

For patterns 1 and 2, the requirements of distances between the neighboring sources and their semidistances are obtained.

So, for pattern 1, the distance between the neighboring sources are:

$\ell = L/(n - 1)$.

The length of equal sections are:

$P\ell = L/[2(n - 1)]$.

For pattern 2, the distance between the neighboring sources are:

$\ell = 2L/(2n - 1)$.

The length of equal sections (semi-distances) are:

$P\ell = L/(2n - 1)$,

where $n$ is the number of pipeline discharge sources, and
$L$ is vehicle length.

The requirements obtained enable the automation of the discharge source arrangement process in the algorithm which, as a result, can estimate longitudinal disturbances.

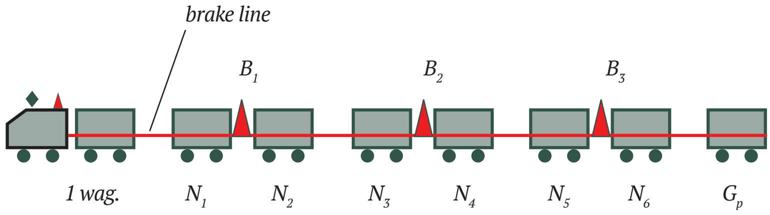



**Fig. 7.** Train arrangement and proposed example of RBUs positioning.

The following options were analyzed in order to solve this problem:

1. The number of wagons in the train (from 10 to 100 with 10-wagon sets) was taken as variable.
2. Symmetric (pattern 1) and asymmetric (pattern 2) arrangements were used as the pipeline discharge arrangement patterns for every train.
3. Various train composition arrangements were considered for the train with the specified number of wagons:
   - 3.1 – homogeneous composition: empty, laden terrain with similar rod stroke for all wagons (minimum and maximum operational values);
   - 3.2 – heterogeneous composition:
     - a wagon with reverse parameters was positioned in different locations along the train;
     - the number of cars with reverse parameters was gradually increased from the front to the rear of the train and conversely with the train length remaining constant.

## Analysis Findings and Recommendations

As a result of the analysis performed, we are able to present the following findings and recommendations.

- the notion of equated length has been introduced[2].
- the maximum irregularity of actual specific brake force values obtained for the deceleration time of a train with a single brake pipeline discharge point are the same as for a train with a similar length.
- in cases where trains consist of more than 50 wagons, are of a similar length, and utilize a multiple-point discharge pattern, the maximum irregularity of actual specific brake force during braking period is constant.
- 30 wagons are recommended as the maximum length for a train using a single discharge point, which means three discharge points are required for a 100-wagon train in case of symmetrical arrangement pattern, and two discharge points when asymmetric arrangement is used.
- the largest maximum irregularity value of actual brake forces during braking time are obtained for an empty train. Irregularity is

decreased by 44-50% in case of a loaded train. This is attributed to the fact that moderate cylinder filling requires more time, which reduces irregularity of brake forces for a loaded train.

– the recommended multiple-point discharge pattern performs best on trains with a homogeneous wagon load and rod stroke. Some progress has also been detected for non-homogeneous trains, and
– the rod stroke variation exercise showed a slight impact on the maximum irregularity value variation, unlike the sensitivity to wagons loading factor.

## Method for RBUs location along long train

A simplified method for identifying the RBUs optimal location has been developed on the basis of these recommendations and the introduction of the notion of the equivalent number of wagons (fig. 7).

$N_n$ - car sequence number from train front end (locomotive);

$B_n$ - RBUs sequence number from train front end (locomotive);

$G_p$ - number of cars in the train (number of the last car in the train);

$G$ - equivalent number of cars (number of cars in an equivalent train).

*Please refer to the recommended values below**

Car number equivalency factor $G_p/G = Kg$;

$Kg^1$ - rounded value of Kg (round upwards to an integer);

Estimated equivalent number of cars

$G_p/ Kg^1 = G^1$;

$G^{11}$ – rounded value of $G^1$; (mathematical rounding rules);

Place of installation of the 1st RBU БХВ (B1)

N1 = 2G11;

N2 = 2G11 + 1 = N1 + 1;

Place of installation of the 2nd RBU (B2)

N3 = N2 + N1;

N4 = N3 + 1;

Place of installation of the 3rd RBU (B3)

N5 = N4 + N1;

N6 = N5 + 1;

Place of installation of the 4th RBU (B4) (not shown at Figure 7)

N7 = N6 + N1;

N8 = N7 + 1;

**Recommended values:*

Number of cars in the train 70 < Gp < 200;

Equivalent number of cars 20 < G < 40,

Recommended value depends on the variety of train wagon load.

The joint research efforts of MTZ TRANSMASH and MIIT have created a new freight train braking system similar in performance to electropneumatic brake systems but without the requirement to re-equip wagons with a homogenous wagon braking system. This was the first time in the history of Russian brake engineering that this was achieved and, critically, the cost of the new system is significantly less than electropneumatic freight train braking systems available from various suppliers. This distributed-control braking system is now regularly operated on trains using the line between Irtyshskoye and Balezino, and there is significant potential to expand this rollout further.

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union of industries of railway equipment

# UIRE

UIRE NP consists of 171 enterprises from 34 Russian regions that manufacture 90% of all rail production in the RF. Goods turnover of the enterprises of the partnership makes up more than 390 billion Russian roubles. Enterprises from Ukraine, Belarus, Germany, Uzbekistan, the Slovak Republic and the Republic of Kazakhstan involved in the activities the partnership.

## COOPERATION OF UIRE NP WITH OUTSIDE ORGANIZATIONS FOR ACHIEVEMENT OF STATUTORY OBJECTIVES OF PARTNERSHIP

European Rail Industry

German Railway Industry Association (VDB)

Austrian Railway Industry Association

French Railway Industry Association

Association of Czech Railway Industry (ACRI)

SWISSRAIL Industry Association (SWISSRAIL)

Association of American Railroads

**Non-profit partnership «Union of industries of Railway Equipment» (NP «UIRE») is founded in June, 2007 in Russia by the companies of Russian Railways, Transmashholding, Kontsern Traktornye zavody and Holding UK «Russian Corporation of transport machine-building»**

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# Application of traction linear motors in various transport systems

**Alexander Galenko,**
Acting Director General of Engineering Research Center (ERC) TEMP,
corresponding member of Russian Academy of Electrical Science

Construction of automated light transport systems designed to transport large numbers of people is experiencing steady growth across the world. Similarly, local computerized freight transportation systems are increasingly being adopted. In many areas a new traction principle, linear induction motors (LIM), is driving these developments following successful tests in Russia.

The traction (motion) principle applied in heavy rail, metro, and tram operation is based on the physical phenomenon of rolling friction (wheel-rail adhesion). Energy transmission and conversion processes predominately lie in electrical energy collection by a pantograph contact shoe from the catenary and its further conversion into mechanical energy by means of rotating traction motors. A traction motor is connected via a gear with a wheel, which due to wheel-rail friction, converts traction motor rotational motion into train motion in a straight line. In other words, a wheel equipped with a drive serves as the vehicle mover and support, while a wheel that does not have a drive offers only a supporting function.

The moving wheel is only possible due to the use of a multi-link energy transmission and conversion system: railway substation – overhead catenary – pantograph contact shoe – traction motor – gear – wheel-rail interface. Each link involves some energy loss, and with an average efficiency of 92-96% for each separate energy transmission link and conversion, the overall efficiency of a traditional transport system does not exceed 50-60%. Furthermore, in standard operating conditions when power supply devices, traction motors, and gearboxes operate beyond their rated duty when in service for a considerable amount of time, the overall efficiency of the transport system is invariably lower than the above figures.

A potential method to conserve energy and simplify this process is to reduce the number of links in the energy transmission and conversion chain, which is achievable in transport systems by altering the traction principle. However, it is widely recognized that no drastic improvement in the performance of technical equipment, including transportation systems, is achievable without transitioning to a new technology.

Infrastructure cost, traction power consumption, ecological and technogenic impact on human health and the environment are mostly determined by the weight and speed of the rolling stock in service. Indeed, car unladen weight per passenger or ton hauled is a widely-accepted measure of vehicle excellence. Clearly the less a vehicle weighs, the less its technogenic impact on infrastructure such as tunnels and elevated structures, surrounding buildings and structures. Rolling stock weight is also inextricably linked with material consumption and the cost of all infrastructure. In addition, rolling stock weight impacts train power consumption, as well as the capacity and weight of wayside facilities and onboard electrical systems.

The weight of a single car may be reduced by 2-2.5 times by using new materials such as composites, as proven in the aviation industry. However, while effective, these materials are expensive. And in the context of the wheel-rail adhesion concept, the solution is inefficient for the overall transport system.

A more feasible solution is to reduce the weight and dimensions of rolling stock through alterations in bogie design. However, achieving this without altering the traction principle has also proven challenging.

Current understanding permits the adoption of electric linear motors to alter the traditional wheel-rail adhesion traction principle into one reliant on electromagnetic field-based traction. Wheel-rail transport systems driven by linear induction motors (LIM) (fig.1) are the most promising systems today. And with no efficient alternative to using a wheel, this should trigger the search for an alternative solution for system support.

One of the first systems using an asynchronous linear motor and resting on wheels has been in service in Vancouver, Canada, since 1986. The 21.4km metro line, including 16.6km of elevated infrastructure, 1.3km tunnel, and 3.5km at grade, is based on the same principle as lines which subsequently opened in Tokyo and Osaka from 1990 (fig.2).

Here the asynchronous linear motor's primary inductor is installed on the bogie, with the linear motor's secondary (reaction rail) located on the track centerline at the railhead. The traction force production principle used here relies on power from the overhead catenary wire, which is drawn through the invertor and transferred to the inductor. This generates a travelling electromagnetic field and interacts with the reaction rail laid between tracks, generating traction force and placing the train into motion.

Existing wheel-rail transport systems based on this traction principle offer some advantages:

– metro construction capex is decreased by 25-30% mainly due to a reduction of the tube's internal diameter from 5.1m to 4m, according to Japanese engineers, and
– the axle load is reduced to 5-6 tons per axle (versus 13-14 tons per axle previously) significantly reducing vibrations and noise.

A transport system utilizing LIMs also consumes less power than a system using rotating traction motors due to fewer energy transfers and conversions.


**Fig. 1.** Transport system using linear induction motor (LIM) technology. Canada

An LIM transport system may be characterized as a light straight line system, which is designed to transport passengers and freight, and runs on a dedicated track. Irrespective of whether it uses conventional rolling stock contact bearings (fig. 1 and 2) or magnetic levitation (pic. 3 and 4), the rolling stock interacts with the track through a supporting system.

The type of contact supports depends on the requirements of the vehicle's bogie. Traditional metal wheels are used in an LIM transport system where LIM solves a tractive effort transmission problem via the wheel-rail interface, and the LIM plane is stabilized perfectly in relation to the secondary system installed in the track.


**Fig. 2.** Subway line using LIM technology. Japan

**Fig. 3.** Very high-speed transport system with electromagnetic suspension. China

**Fig. 4.** Tobu HSST Maglev Line. Japan

The application of supporting pneumatic-tyred wheels contributes to significant reduction of noise but creates additional difficulties for keeping LIM stabilized at the track bed.

The distinctive feature of magnetically levitated rolling stock is the lack of wheels to provide support, direction and to transmit traction force between the rolling stock and track. Instead the rolling stock is supported and stabilized over the guideway at a distance of 10-15 mm with permanent magnet levitation or 100-300 mm where electrodynamic levitation utilises superconductive magnets. The system is put into motion by a non-contact electric linear motor. It transforms electric power into linear motion without intermediate mechanical links. And without a conventional wheel adhesion system for motion and stability, there are no limits on speed, even when encountering gradients.

Maglev rolling stock also offer significantly lower loads thus reducing wear on the line. Indeed, according to international experts, maglev track repair and maintenance costs are around 15-20% of the costs of rail-based systems.

The electromagnetic suspension power intake of the most common electromagnetic levitation system ranges from 1.0 to 1.5 kW/t, constituting about 5% of drive power. In addition, the overall power consumption of electromagnetic levitation transport system running at speeds of up to 100-200 km/h is comparable with the power consumption of railway vehicles. Tests have shown that even at very high speeds, maglev vehicles consume 10-12% less power than equivalent railway rolling stock.

ERC TEMP has compared three configurations of a LIM-based vehicle with different rolling stock support systems – steel flanged wheel, pneumatic-tired wheel and magnetic levitation. The studies encompassed an initial feasibility study, design and engineering development, and culminating with prototype testing performed on a special 850m test track at ERC TEMP's facilities in Ramenskoe, Moscow Region (fig. 5).

ERC TEMP's solution, first developed in 1996, is based on a tyred wheel traction linear drive configuration. This solution, which integrates the traction linear drive, is unique in that it combines an asynchronous linear motor with pneumatic-tyred wheels and a guide rail to fulfil several technical functions: clearance stabilization, and a trolley and guideway for pneumatic-tyred wheels. The success of these experiments and trials ultimately provided

**Pic. 5.** Testing of 18 ton TP-05 car using traction electric linear motor and magnetic suspension

sufficient practical background evidence to implement the traction electric linear motor into commercial transport systems.

The joint efforts of engineers from ERC TEMP and Moscow Monorail Roads led to the implementation of LIM on the Moscow Monorail Line (fig. 6) in November 2004. The rolling stock running on the line rests on pneumatic-tyred wheels which serve only as support.

During the same period, ERC TEMP began developing an autonomous freight transport system. In order to handle structural panels from a workshop to the loading platform, a transport system comprising three trolleys (one trolley with the capacity of 12 tons and two trolleys of 30 tons) was built and put into service at a house-building facility in Rostov-on-Don in 2008. The trolleys are supported by metal-flanged wheels and are equipped with battery-driven LIMs.

Further work is currently underway to create a track-based transport system that utilizes LIMs positioned in the track.

This transport system offers the following advantages:

– reduction of bogie weight by about 30%;
– fully automated solution due to the installation of LIMs in the track;

**Fig. 6.** Moscow monorail system

– potential to increase speeds to 300km/h;
– no electric power transmission elements; vehicle operation with autonomous power supply source.

Further possible applications for LIM systems, include: local rapid passenger and freight transportation systems; very high-speed passenger and long-distance freight transport systems; integration into various existing freight handling systems to offer greater automation; and in auxiliary traction equipment used to negotiate sharp gradients.

CONGRATULATIONS

# On August 10th, Michaela Stöckli, Director of SWISSRAIL Industry Association celebrates her birthday anniversary!

Dear Michaela,

Please, find sincere our congratulations on the occasion of your birthday.

You are known to us as a highly competent leader of SWISSRAIL Industry Association, and many of Swiss Federal Railways' greatest achievements are largely down to your unfailing energy, tireless efforts and commitment to success. You always handle challenges with natural tact, humor and optimism. Your charisma and openness, kindliness and professionalism have established a strong basis for the friendship between our associations, and every one of our meetings reinforces our desire to improve and deepen our cooperation.

We wish you, Michaela, good health and look forward to reporting new achievements through our joint efforts in the months and years to come. We also want to wish your family and colleagues every happiness and success for the future.

*Yours sincerely,*
*Valentin Gapanovich*
*President, Union of Industries of Railway Equipment*

# Russian Association of Railway Equipment Industry celebrates its 10th Anniversary

In the entire course of history, 10 years is a very short space of time. But for an institution committed to achieving its objectives, and when all representatives are working together towards a specific objective, a great deal can and has been accomplished in this period. The Union of Industries of Railway Equipment (UIRE) was established on June 14th 2007. Its founder and president is Valentin Gapanovitch, and the association consists of 174 member-companies from 34 federal states of the Russian Federation. Together the member companies are responsible for almost 90% of Russia's total railway industrial output.

The primary purpose of the association, as defined during its foundation, is to promote innovation and the technical development of railway manufacturing in Russia. It is working in the following areas to help its members achieve this objective:

- facilitating technical policy implementation;
- providing assistance to create a new generation of rolling stock and sophisticated products;
- establishing and building a technical regulation system;
- creating a new regulatory framework, including a system of national industrial standards
- improving quality management systems, implement IRIS, and convert to ISO;
- developing a certification system for the railway machine building industry.

In September 2014, a major milestone was reached when both associations released a booklet outlining the regulatory framework for conformity assessment and authorization of railway products in the Customs Union and the EU. A second publication, unveiled in September 2016, contemplates regulatory changes both in the Customs Union and the EU... The cooperation between UNIFE and NPUIRE is crucial for the continued development of both Russia and the EU's railways and economies.

*Philippe Citroën,*
*Director General, European Rail Industry Association (UNIFE)*

OPZT is structured in suh a way to offer its members opportunities to actively participate in its committees, sub-committees and sections. As a result members direct the organisation's activities, and can freely address any urgent and pressing issues during any structural transformation. This well-developed system provides sufficient resources to offer an effective decision-making process, which is able to deliver real results.

Leading industry representatives now make-up 11 committees, almost all of which consist of several sub-committees. For instance, the Committee for Locomotive Building and Locomotive Components has five working sections:

- newly advanced developments;
- railway product quality;
- cooperation of railway product manufacturers;
- technical regulation and product certification;
- rolling stock safety.

In addition, the Freight Rolling Stock Committee integrates four sub-committees:

- rolling stock building;
- rolling stock operation;
- rolling stock maintenance;
- automatic braking.

The association also provides committees for quality, regulatory and engineering support and standardization; development and introduction of intelligent control systems and safety systems; and coordination of manufacturers of infrastructure components and maintenance vehicles.

Awarding of Oleg Senkovsky, First Deputy of Head of Technical Audit Center, RZD (on the left)

Anniversary conference "The Russian Railway Industry Association: progress made from 2007 to 2017 and development outlook", Cheboksary

OPZT is celebrating its 10th anniversary, which is an event of an international importance... I am very pleased by this, and I would like to emphasize that the SWISSRAIL Industry Association has been an official partner of the OPZT for 5 years.

*Michaela Stöckli, Director*
*SWISSRAIL Industry Association*

The Metallurgy Manufacturers Coordination Committee includes two sections: wheelset component production, and rail-rolling products.

Among the other committees is the Export and Innovation Committee; Intellectual Property Committee; Technical Regulation & Safety Committee, while the association also has two councils: the Council of Certification Institutions & Test Laboratories, and the Design and Engineering Council.

The efforts of these committees have brought numerous achievements. For instance, they facilitated the creation of new locomotive and freight wagon lines, and new types of passenger coaches which offer enhanced comfort and integrate bolsterless bogies. In addition, they support the adoption of new requirements for freight wagon bogie side frames, and the use of highly-efficient dampers, rail wheels with improved hardness and wear parameters, and state-of-the-art IT-based locomotive control systems, brake control systems, diagnostic and safety systems, and updated train management systems. Critically, a huge amount of work has been invested in creating an environment ready for the introduction of high-speed trains and establishing Russian facilities with the capability to

Since 2013, both our Railway Industry Associations, OPZT and VDB, have been brought together through an open, constructive and forward-looking dialogue. Russia and Germany are two large railway countries with rich traditions and good partnerships.

*Dipl.-Ing. Axel Schuppe, General Manager*
*The German Railway Industry*
*Association (VDB)*


Head of Chuvashi Republic M.V. Ignatyev and V.A. Gapanovich

Igor MIKHALKIN, General Director INFOTRANS, Branko Kovačević, Owner of Kovačević Engineering , and Valentin Gapanovich (from L to R) after signature of Agreement on Cooperation and Partnership

produce various components for cutting-edge rolling stock.

In order to respond to these changing times, the association participates in and hosts international industry events, including the International Fair of Railway Equipment and Technologies, EXPO 1520, which is held every two years.

As a result of successful Russian participation in the IRIS Advisory Boards, the International Railway Industry Standard was translated into Russian. Aligning Russian regulations with international requirements remains a continuing process.

Other activities focus on developing and strengthening relations between Russian and international business communities, regional industry development authorities, and in the creation of industrial clusters.

As a part of anniversary celebration programme, a conference “The Russian Non-commercial Association of the Railway Industry: track record (2007-2017) and expected future development” was held on July 7 in the Chuvashi Republic, Russia. During the event, many of the conference participants, including plant general managers, design directors, design leaders and OPZT vice-presidents, were awarded for their contribution to the development and activities of the association.

The Anniversary Conference Resolution, the outcome document adopted at the event, highlighted major achievements and future priorities for the association. Conference participants expressed shared and strong confidence that through joint efforts of all members, the association can effectively address development problems and successfully meet contemporary challenges.

After 10 years of good progress, the OPZT remains an active player with ambitious plans for further development of the railway industry.

...I would like to wish you, and all of us together, successful progress in the development and modernization of the global railway network as well as urban rail systems, and will be glad to continue our cooperation in this respect.

*Dipl.-Ing. Thomas Karl, Präsident*
*The Austrian Railway Industry Association*

Members of the the Russian Railway Industry Association at the Anniversary conference

The European companies working in the Russian market share the same core principles outlined in OPZT’s Charter: to act as responsible businesses, create innovative high-quality products, improve the regulatory framework in order to ensure safety and quality, and to improve facilities' energy performance.

*Dr. Frank Schauff,*
*Chief Executive Officer*

*Dr. Thomas Staertzel,*
*Chairman of the Board*

*Philippe Pegorier,*
*Member of the Board,*
*Chairman of the Machine Building & Engineering Committee*
*The Association of European Businesses (AEB)*

# Russia's railway Test Loop celebrates its 85th birthday


**Alexander Savin,**
Dr.-Ing., Deputy Director General,
Test Center Manager, VNIIZhT
(Russian R&D Institute
of Rail Transport)

**Elizabeth Matveeva,**
Executive Editor
of Railway Equipment
Journal


The Experimental Institute of Railways (currently known as VNIIZhT) was founded in 1918 following the establishment of an 'Experimental Bureau' in Moscow. Upgrading the capability of railway motive power was a major issue at the time, and in order to offer comprehensive investigation of the topic, the institute required a special circle-shaped test track located in a perfectly flat location. A proposal to build a special railway loop for locomotive trials was initiated by Alexey Dolinzhev, an employee of the Institute for Motive Power Modernization. His proposal was derived from the understanding that a special closed and level profile railway loop was required to study steam locomotives parameters, a proposal for which was put forward as early as 1901 by Prof. Yury Lomonosov, the pioneer of Russian locomotive performance testing. The idea was finally realised in 1932 with the creation of a loop designed for testing various rolling stock, and railway components and systems in real-life conditions. For the first time in the world, the facility would combine the accuracy of laboratory-based tests with field operating conditions.

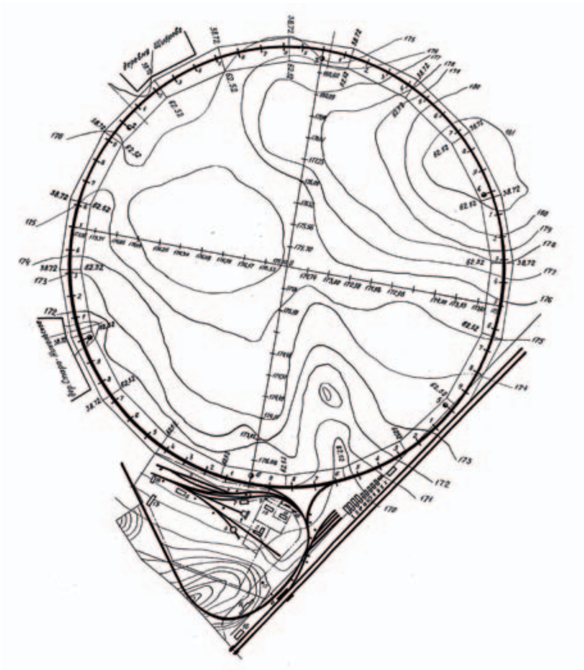
## Site selection and construction

In light of the explosive growth of Moscow in the 1920s, the People's Commissariat for Railways was unable to acquire a suitable testing site within close vicinity of the capital. The first potential site was identified near Lyublino station on the Moscow-Kursk Railway. However, it was immediately rejected as the proposed area was occupied with irrigation fields.

Another option was Butovo station. This was also rejected, this time on the understanding that the testing facilities would be electrified in the future and the potential problems this might cause with special-purpose installations by the People's Commissariat for Communications in the proposed area, which should not be exposed to high voltages.

The third option, which ultimately succeeded, was a site near Scherbinka.

Construction of the test loop was supervised by Prof. Dr.-Ing. Nicholas Belokon, a prominent science and technology master. The loop was designed as a 6km closed track with a fixed radius of 956m. Additional facilities included locomotive and wagon depots, a railway sub-station, workshops and laboratories. From the start, the test loop was Russia's largest integrated facility for testing railway equipment,



Test loop layout

Yury Lomonosov
(1876-1952)

Since its foundation and up to 1960, the test loop was unique as the world's only railway testing facility with ring-shaped test track.

with the capability to thoroughly test the compatibility of all new solutions for rolling stock, track, catenary, and automatic control systems in potentially challenging operating conditions. The test loop also offered institute experts the capacity to perform design validation tests and predict the long-term performance of components. For example, breakthrough studies of rolling stock and track interaction using new test instruments were initiated at the test loop when it opened and have continued throughout its existence.

## Launch into operation

Between 1932 and 1935 the site was known as the Test Loop of the Institute for Motive Power Modernization of the People's Commissariat for Railways, with Prof. Dr.-Ing. Valentin Egorchenko the acting manager of the testing facility.

The site's primary purpose was to perform traction tests of diesel and electric locomotives. The first unit tested on the loop was a steam-locomotive EMO 710-53, with tests led by Prof. Oganes Isaakyan. The first diesel locomotive EEL14 was tested under the supervision of Dr.-Ing. Timofey Hokhlov in 1933. Comprehensive tests of automatic coupler solutions also started in 1934, and ultimately led to the development of the SA 3 coupler.

The institute also developed criteria to evaluate the impact of locomotives on the track in order to avoid sudden rail breakages, dangerous shears, and serious accumulations of track defects, as a result, significantly improving the safety of railway operations. In addition, assessments of locomotive underframe quality introduced during the acceptance test phase substantially enhanced locomotive reliability.

## Electrification and new tests

Electrification of the test loop occurred at the same time as the roll out of electric services on suburban and long-distance lines in the industrial areas of the Urals, the Kuznetsk Basin, and southern Russia. The electrification of the loop offered substantial opportunities to investigate power installations and electric rolling stock, including the first tests of the VL19-17 and S11-18 DC locomotives conducted under the supervision of Prof. Valentin Egorchenko. The testing site was subsequently renamed as the Test Loop of the Central Research Institute of the People's Commissariat for Railways, and Alexey Egorov was appointed site manager.

Among the achievements during this period was the recommendation of extensive AC electrification on the national railway network following AC supply tests at the facility. In addition, the first serial VL60 AC locomotive with ignitron rectifiers was put into operation after comprehensive tests on the loop.

At the same time, research and test institution engineers and experts were working on identifying testing methods for rolling stock and power installations as well as creating automated data acquisition and processing systems for laboratory vehicles.

From 1936, the team began testing brake shoes, which were initially fabricated from cast iron, and later from various composite materials.

Between 1936 and 1937, the loop was engaged in extensive dynamic tests of four-axle freight gondola wagons using bogies with various springs, and four-axle passenger coaches which used five basic bogie types.

The first domestic OR22 AC locomotive was tested under the supervision of engineers V A Zabrodin and E G Lutsenko in the winter of 1939-40, followed by testing of 25kV single-phase AC locomotives, and electric braking systems for locomotives. This led to the development of the world's most powerful AC freight locomotives – VL80T, which used dynamic brakes, and VL80R, which uses regenerative brakes. Enhanced power locomotives with brushless traction motors – VL80B (synchronous) и VL80A (asynchronous) – were also developed and successfully tested at the site.

These new locomotives offered a uniform speed for freight trains travelling on gradient tracks, reduced brake shoe wear, while a new regenerative braking system fed 10-12% of the energy consumed for traction back into the supply system. A large team of industrial and transport experts from the institute, including Boris Nikiforov, D.Sc. in Engineering, and A L Lisitsyn, Ph.D Tech., received a state award in 1974 for developing the VL80T locomotive.

During the 1940s extensive research was undertaken at the test loop relating to the introduction of AC electric locomotives.

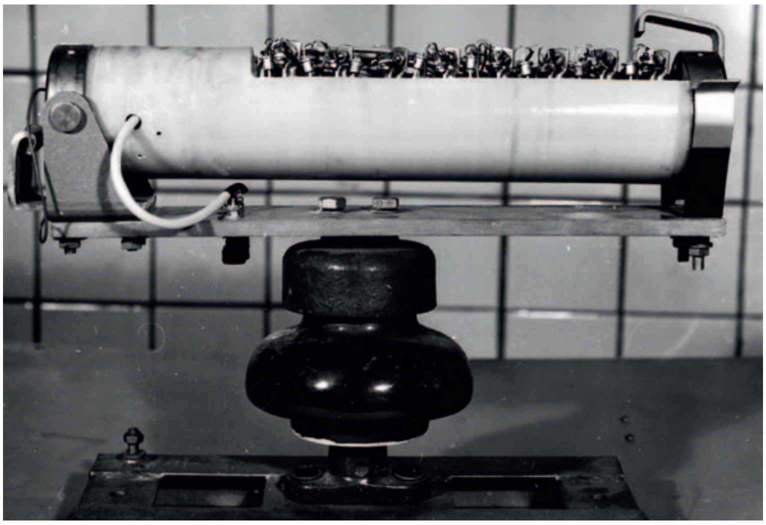
During WWII from 1941 to 1945, with Alex Egorov leading research efforts, the test loop successfully validated the institute's recommendations for upgrades to the locomotive fleet. Changes included creating mobile locomotive convoys; changing and checking locomotive maintenance regulations to match wartime conditions; use of low-grade coals; and the conversion of power stations to use coal-derived gas.

Well-known Russian wagon maintenance experts, Michael Vinokurov and Sergey Vershinsky, were also engaged in work at the centre to identify optimal methods to repair damaged wagons, replace worn-parts and improve in-field wagon repair methods. Prof. Sergey Vedenkin, in cooperation with specialists of WWII frontline roads, also arranged the replacement of hard and corrosive waters at every depot. In addition, there was an emphasis on developing diesel vehicles for use predominately on the Ashgabat railway. The team, led by Prof. Kirill Shishkin, carried out studies aimed at improving diesel locomotive design, traction performance and operating characteristics.

In the post-war period, and in particular during the 1950-70s, the institute continued to carry out research aimed at further developing rail transport in Russia. During this period, the institute was led initially by Prof. Dr.sc.oec. Tigran Khachaturov, a distinguished economist and a member of the Academy of Science of the USSR. He was followed in 1950 by Vasily Kurochkin, a prominent senior railway officer, and from 1951 to 1962 by Ivan Ivanov, PhD Tech, and a major figure in the sphere of track maintenance, and holder of the title Hero of Socialist Labour. From 1962 to 1978 the position was filled by Prof. Dr.-Ing. Alexey Karetnikov, a leading railway operations scientist, a prominent individual in research engineering, and honored master of sciences and engineering of the Russian Soviet Republic.

Throughout this period, these leading individuals directed the institute's research programs. This included work to improve railway

Substation



HV circuit breaker for line signaling
used to protect 1,25 kW signaling line transformers, replaced quartz-sand fuses
nominal voltage – 10 (6) kV
breaking current – 1,6 (2, 3) A.
action time – from 4 to 12 sec.
ensures 15-20% better reliability of power supply systems

Laboratory car No 2208 for dynamic tests, 1940


Track laboratory. First row: A.I. Kolesnikov, interns.
Second row: L.A. Greshchinkov, M.F. Verigo, B.S. Kosarev,
O.P. Ershkov, M.A. Alekseev. I.P. Pavlov, E.M. Bromberg

operation, locomotive fleet performance, and track infrastructure. They also facilitated the rise of new areas of knowledge, including railway transport economics, freight and commercial operation, electric and diesel haulage, energy systems, wagon fleet management, automatic brake theory, bridge and tunnel management, metallurgical science, welding, automatic controls, telecommunications and signaling, and computer engineering.

The last 6,000hp articulated design steam locomotive P38.0001 with a 1-4+4-2 wheel arrangement was tested in 1955.

Among the notable research activities were efforts to prolong the life of worn parts through build-up welding, improving the quality of continuous rail welds, and repairing damaged rails through resistance welding. Indeed, the welding department team managed in a short period of time to validate the feasibility of resistance welding for domestic rails. However, large-scale implementation of this welding method was restricted by a lack of rail welding machines. This, and a number of other challenges, were successfully addressed by the welding department team, and in particular by Alexander Nazarov, a reknowned progressive welder and honored inventor of the Russian Soviet Republic, who joined the team in 1952.

At the beginning of the 1950s field observations as well as tests of the supply network and facilities, and current-collection processes were carried out. The test loop was used to study mechanical interaction between pantographs and catenary, as well as to better understand the characteristics of current collection in case of icing of wires and components. Investigations were also carried out into contact wire wear and heating, corrosion protection for catenary supports, and to develop insulators using polymer insulating elements.

In 1958 the loop witnessed studies of axial forces generated during braking of an 8000-ton train. And between 1958 and 1959 two additional test loops for track structure testing were built inside the main circular loop. These loops possess variable gradients and profiles, straight sections and curves ranging from 390m to 1220m.

The first loop was built for testing all types of rolling stock.

The second and third loops are 5.7km in length and were intended for testing prototype track types, roadbed, track machines and equipment, as well as to conduct rolling stock operational tests. This includes tests in variable-radius curves of 400m and above, straight sections, and rising and falling gradients. The jointed track used included R65 type rails, concrete sleepers, KB rail fastenings (terminal-bolted), ZhBR-65 (direct fixation), and ARS (clip) series; R65 series switches, grade 1/11 frogs. In addition, rail circuits were equipped with DSSh-13 track relays, and KTSM-01, KTSM-02 hot box detection systems.

Track buckling tests

First, second and third circular tracks of test loop, 1970s

By having access to two loops with similar profiles and gradients, engineers were able to study the interaction between different track layouts and rolling stock, and to validate already obtained results. The total length of test loops together with entry lines, links and testing sections is now around 42km.

Completion of the second and third loops also provided additional testing facilities for trains weighing up to 10,000 tonnes and which could run for more than 500km per day. The test loop trials improved testing times by eight to 10 times compared with similar tests on main line tracks. They also provided very reliable data on the performance of wagons, and components in existing and potential operating conditions.

Similar railway test facilities appeared in China in 1960, in Czechoslovakia in 1963, and in the United States in 1980.

The development of new solutions designed to haul heavy trains and high axle load locomotives at 140km/h (120km/h through switches)

Second test loop shunting zone and locomotive building, 1970s

In 1981 the facility was renamed the Test Loop of Federal State Unitary Enterprise Russian R&D Institute of Rail Transport (VNIIZhT) of the Ministry of Railways.

required upgrades to superstructures. This included the installation of new R65 rails with a 90mm superelevation, and a new switch on the curved track.

Between 1969 and 1970, the test facilities were used for unique integrated dynamic analysis of a non-uniform freight train with a maximum weight of 15,000 tons and which consisted of high-capacity wagons with locomotives positioned both at the head and in the middle of the train.

A flyover bridge, which can accommodate 12 spans and consisting of various metal and concrete structures, was also erected in the 1980s.

More than 100 different locomotives, EMUs and DMUs have been tested on the test loop since it opened. This includes in 1993 a TEP80 passenger diesel locomotive with 2o+2o-2o+2o wheel arrangement that subsequently operated at a record 271km/h during trials on St.Petersburg – Moscow line.

Vladimir Kozlovsky was appointed site manager and the construction of exhibition halls and a second shunting yard was completed on the site in the same year.

Construction of an automatic interlocking control system for switches and signals was subsequently completed in 1987, and from 1993 to 1999 the faciltiy was used to test EP1 AC locomotives, dual voltage EP10 locomotives with asynchronous traction motors, and the high-speed passenger locomotive EP200. In 2001, the ES250 Sokol, or Falcon, high-speed train underwent test runs.

## Test loop today

Today the facility continues to offer end-to-end testing of railway vehicles. Facilities include office and utility buildings, which house administrative departments, the track department, traction substation, sand dryer, pump house, and buildings for static tests. Current test loop infrastructure comprises three single-track loops, connecting switches, and power equipment to supply catenary at 825V and 3kV DC, and 25kV 50Hz AC.

The unique testing facility and favorable climate conditions allow for various tests to take place, including system level dynamic tests which reveal the impact of new and upgraded rolling stock on track as well as testing of new switch solutions, brakes, pantograph contact, and different types of overhead catenary. The infrastructure also enables testing of rolling stock and track with boundary power supply values and under specified track profile parameters.

Today the test loop is headed by Valery Kaplin.

The study of interaction of track and rolling stock is among the facilty's ongoing projects. Teams have found the correlation between increasing axle loads of 25, 27, and 30 tonnes and fatigue-related defects of the top of rail and the reliability of freight wagon components.

At present, an 8,500-ton freight train consisting of 85 gondola wagons is running daily on the second loop, reaching speeds of 80km/h, and taking the gross annual tonnage of the loop to 300 million tons.

Since the test loop was created, many types of domestic and foreign railway equipment have been tested, including:

- more than 100 prototype and modified locomotives, EMUs and DMUs including the Velaro RUS or Sapsan EMU, Talgo trains, Allegro, Desiro RUS or Lastochka EMU, EG2Tv, and RA-2,
- freight wagons and passenger coaches
- rolling stock subsystems undergoing durability and reliability checks
- endurance tests of track structures, and
- safety control devices, resource-saving and energy-saving solutions and other process equipment.

The facilities offer not only system-level tests but can also test components and subsystems in special laboratories, and using state-of-the-art test bench equipment. This includes a a 5,200 ton wall for front of vehicle impact tests and a test bench for couplers, a wheelset laboratory, and laboratory for testing passenger vehicle electrical equipment. The laboratory for testing brake systems, including friction elements, is equipped with a unique test bench that allows testing of brake shoes and pads installed on real wheels and disks at speeds of up to 300km/h and at a 25 tonne axle load.

The electric rolling stock laboratory has the capability to test:

- traction motors, voltage control systems, catenary thyristor transducers with the possibility of installing any hanger type, and
- car strength using impact testing machines and a test bench capable of creating longitudinal stress of ±500 tons and a vertical load of up to 300 tons.

## Venue for international rail events

International Fair Rolling Stock '71, July 1-20, 1971

International Fair Rolling Stock '71. Electric locomotives

During the 1970s and 1980s the test facility became a center for international rail exhibitons and events which served as a forum for introducing best practice for national and international rail companies and operators. The international events, Rolling Stock '71 and Railway Transport '77, were attended by hundreds of foreign companies and thousands of local specialists representing domestic railway manufacturers and operators. Contracts for the supply of significant quantities of equipment were signed between the Ministry of Railways, Branch Ministries of the USSR, and foreign companies during both exhibitions.

International Fair Rolling Stock '71. 2TE116 diesel locomotive, USSR

Two further large international fairs, known as Railway Transport, were organized and hosted by VNIIZhT at the centre in 1986 and 1989, both of which were attended by delegates from around 20 countries.

In 2007 the first international railway fair, EXPO 1520, was held. The goal of the event, which is now held every two years, is to integrate Russia into international railway community and facilitate a mutually beneficial cooperation between domestic and foreign manufacturers and suppliers.

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