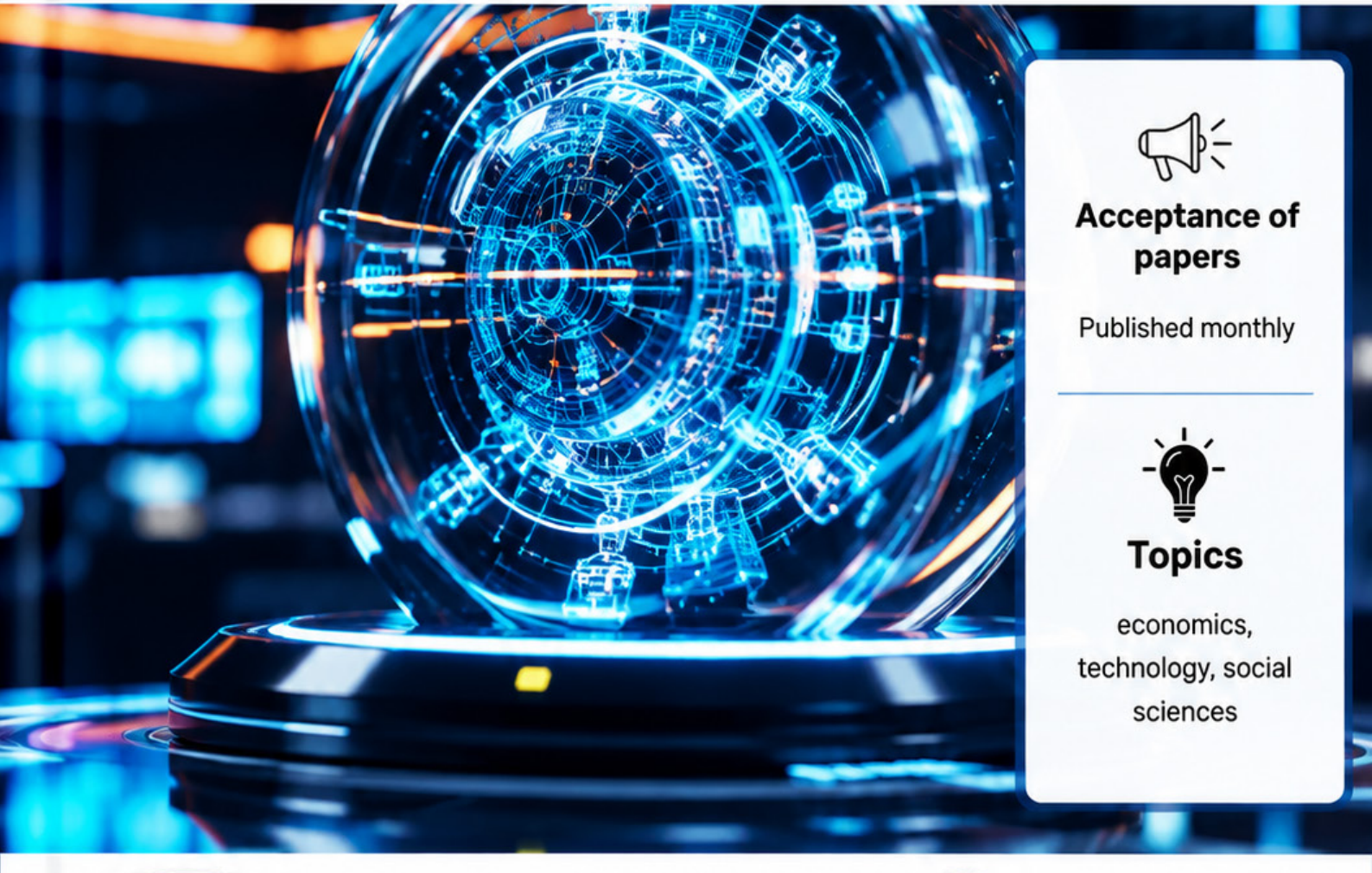
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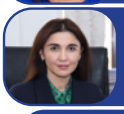

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AN INTEGRATED METHODOLOGICAL MODEL FOR DEVELOPING RAILWAY ENGINEERING ON THE BASIS OF INDUSTRIAL COOPERATION

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Annotatsiya. Maqolada temir yo‘l mashinasozligini sanoat kooperatsiyasi asosida rivojlantirishning yaxlit metodologik modeli ishlab chiqilgan. Model maqsadlarni belgilash, diagnostika, kooperatsiyani loyihalash, iqtisodiy asoslash, institutsional qo‘llab-quvvatlash, amalga oshirish, baholash va monitoringdan iborat sakkizta funksional blokni qayta aloqaga ega yopiq boshqaruv sikliga birlashtiradi. Modelning asosini ishlab chiqarish hajmining yig‘ish quvvati, tor bo‘g‘inning o‘tkazuvchanligi va butlovchi qismlar ta’minoti imkoniyatlaridan eng kichigi bilan cheklanishi sharti tashkil etadi. Model O‘zbekistonning 2026–2030-yillarga mo‘ljallangan harakatlanuvchi tarkibni yangilash dasturiga oid rasmiy ma’lumotlar asosida uchta ssenariy bo‘yicha sinovdan o‘tkazilgan.

Kalit so‘zlar: temir yo‘l mashinasozligi, sanoat kooperatsiyasi, metodologik model, tizimli yondashuv, ssenariy tahlili, mantiqiy model, monitoring.

Аннотация. В статье разработана комплексная методологическая модель развития железнодорожного машиностроения на основе промышленной кооперации. Модель объединяет восемь функциональных блоков — целеполагание, диагностику, проектирование кооперации, экономическое обоснование, институциональную поддержку, реализацию, оценку и мониторинг — в замкнутый управленческий цикл с обратной связью. В её основе лежит условие, согласно которому объём выпуска ограничивается минимальным значением сборочной мощности, пропускной способности узкого места и возможностей поставок комплектующих. Модель апробирована по трём сценариям на официальных данных программы обновления подвижного состава Узбекистана на 2026–2030 гг.

Ключевые слова: железнодорожное машиностроение, промышленная кооперация, методологическая модель, системный подход, сценарный анализ, логическая модель, мониторинг.

Abstract. The article develops an integrated methodological model for advancing railway engineering through industrial cooperation. The model combines eight functional blocks — goal setting, diagnostics, cooperation design, economic justification, institutional support, implementation, assessment and monitoring — into a closed management cycle with feedback. At its core is the condition that output is constrained by the minimum of assembly capacity, bottleneck throughput and component supply capacity. The model is tested under three scenarios using official data on Uzbekistan’s rolling stock renewal programme for 2026–2030.

Keywords: railway engineering, industrial cooperation, methodological model, systems approach, scenario analysis, logic model, monitoring.

INTRODUCTION

The development of railway engineering in Uzbekistan is governed by several groups of decisions: strategic documents [1], sectoral legislation [2], acts on industrial cooperation [3; 4] and rolling stock renewal programmes, which envisage the production of 10,000 freight wagons in 2026–2030 [5] and an instruction to increase capacity to 2,000 wagons per year [6]. Each group of decisions relies on its own indicators and instruments, but there is no single methodology linking goals, diagnostics, the choice of cooperation forms, economic justification and monitoring.

Without such a link, support measures risk missing their goal: for example, expanding assembly capacity will not increase output if the constraint lies in component supply. **The aim of the study** is to develop an integrated methodological model[1] for developing railway engineering on the basis of industrial cooperation and to test it on official data.

1 A methodological model is an ordered set of interrelated blocks, methods and indicators describing the sequence of making and verifying management decisions.

LITERATURE REVIEW

The methodological basis for integration is L. von Bertalanffy's general system theory, which views an object as a set of interrelated elements whose properties cannot be reduced to those of its parts [7]. G.B. Kleiner applied the systems approach to the enterprise as an element of meso-economic structures [8]. Programme management widely uses the logic model "resources — activities — outputs — outcomes" [9], and continuous improvement relies on W. Deming's plan–do–check–act (PDCA) cycle [10]. R. Kaplan and D. Norton proposed linking strategy with measurable indicators through the balanced scorecard [11].

The substantive elements of the model draw on O. Williamson's transaction cost theory, which determines the choice of cooperation form [12], P. Joskow's empirical findings on contract duration under specific investments [13], the typology of value chain governance by G. Gereffi and co-authors [14], R. Hausmann and D. Rodrik's concept of industrial policy as "self-discovery" [15], E. Goldratt's theory of constraints [16] and the OECD methodology for composite indicators [17]. In the Uzbek literature, A.A. Zoxidov developed a mechanism for managing the transport system [18], F.S. Saidmurodov a mechanism of state regulation of railways [19], and B.B. Mullabaev a model of vertical integration of industries [20]. However, no model combining these approaches for railway engineering has been proposed. The correspondence between approaches and model blocks is shown in Table 1.

Table 1.
Theoretical and methodological foundations of the model blocks[2]

Approach	**Source**	**Role in the model**
Systems approach	L. von Bertalanffy [7]; G.B. Kleiner [8]	Structure of the model as an integrated system of blocks
Logic model and PDCA	W.K. Kellogg Foundation [9]; W. Deming [10]	Sequence "goal — action — result" and feedback
Transaction costs, contracts	O. Williamson [12]; P. Joskow [13]	Choice of cooperation form and contract term (blocks 3–4)
Value chains, industrial policy	G. Gereffi [14]; R. Hausmann, D. Rodrik [15]	Localisation stages and institutional support (blocks 3, 5)
Theory of constraints	E. Goldratt [16]	Model core: output is determined by the bottleneck (blocks 2, 6)
Composite indicators	OECD [17]	Integral assessment (block 7)

RESEARCH METHODOLOGY

The study uses the systems approach, logic modelling, the balance method and scenario analysis. The core of the model is formalised by the condition:

$$Q_t = \min(M_t \cdot U_t;\ B_t;\ S_t), \quad \Sigma_t\, Q_t \geq Q_{prog},$$

where Q_t is output in year t; M_t is assembly capacity; U_t is its achievable utilisation rate; B_t is the throughput of the bottleneck (casting, welding, bogie assembly); S_t is the volume of component supply, including supply through cooperation; and Q_{prog} is the programme volume. The condition reflects the conclusion of the theory of constraints [16]: increasing capacity M_t alone does not raise output if B_t or S_t is binding. Official data on capacity and programmes were used for testing [21; 5; 6].

ANALYSIS AND RESULTS

Model architecture. The model includes eight blocks connected by direct and feedback links (Figure 1).

2 Developed by the author based on the sources cited in the table.

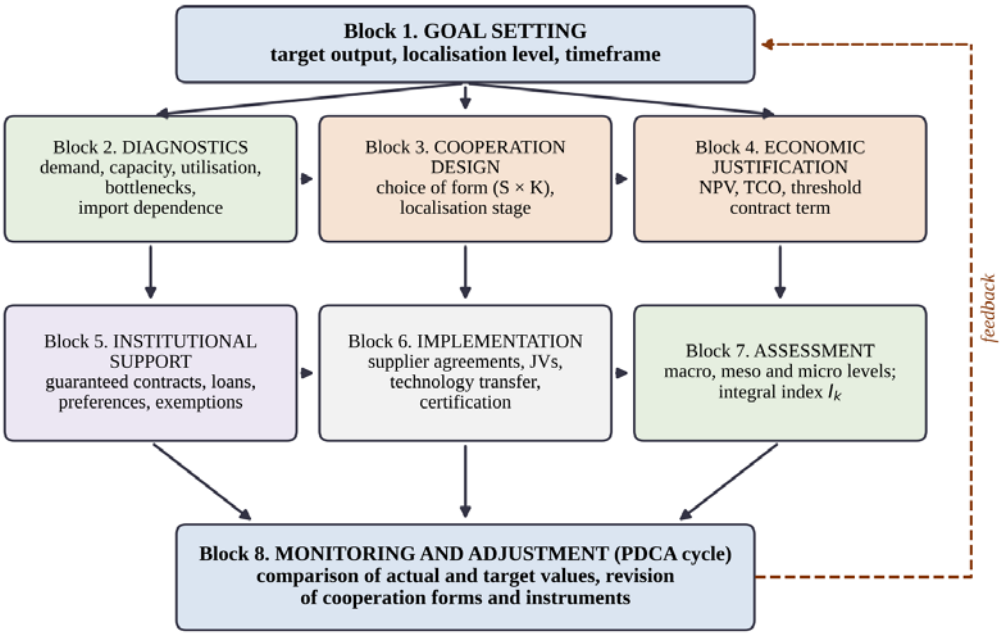


Figure 1. Integrated methodological model for developing railway engineering on the basis of industrial cooperation[3]

The content of the blocks, methods used and data sources are given in Table 2. The goal-setting block sets programme volumes and target localisation levels; the diagnostics, design and economic justification blocks shape the decision on the form of cooperation; the support, implementation and assessment blocks ensure its execution and measurement; and the monitoring block compares actual results with targets and initiates adjustment.

Table 2.
Content of the integrated model blocks[4]

Block	Key indicators	Methods and tools	Data sources
1. Goal setting	Programme output, target capacity, localisation level	Logic model, BSC	Programmes and instructions [5; 6]
2. Diagnostics	Capacity utilisation, bottlenecks, import share	Balance method, theory of constraints	Enterprise data [21]
3. Cooperation design	Asset specificity, technological complexity	Form selection matrix, localisation stage model	Process charts, supplier market
4. Economic justification	NPV, TCO, threshold contract term	Discounting, sensitivity analysis	Loan and procurement parameters [4]
5. Institutional support	Volume of guaranteed purchases and concessional loans	Guaranteed contracts, preferences, exemptions	2026 Decree [4], PQ-99 [3]
6. Implementation	Number of agreements, JVs, certified products	Contracts, JVs, technology transfer	TR CU 001/2011 [22]
7. Assessment	Integral index, meso- and macro-level indicators	Composite index, AHP	OECD methodology [17]
8. Monitoring	Deviation of actual results from targets	PDCA cycle	Reporting on renewal programmes

Testing the model: scenario analysis. To test the model core, three scenarios of freight wagon output for 2026–2030 were calculated (Table 3). Input data: current capacity of about 1,333 wagons per year (derived from the instruction to increase capacity 1.5-fold to 2,000 wagons) [6] and a programme of 10,000 wagons [5].

3 Developed by the author.
4 Developed by the author.

Table 3.
Freight wagon output scenarios for 2026–2030[5]

Scenario	Assumptions	Output over 5 years, units	Programme completion, %
S1 Inertial	Capacity is not increased; utilisation at the level of the second-stage plan (954 wagons per year)	4,770	47.7
S2 Capacity expansion without cooperation	Capacity of 2,000 units from 2027; the bottleneck remains, utilisation 80%	7,466	74.7
S3 Cooperation-based	Capacity of 2,000 units from 2027; component supply through cooperation removes the constraint; utilisation 90% in 2026 and 100% thereafter	9,200	92.0

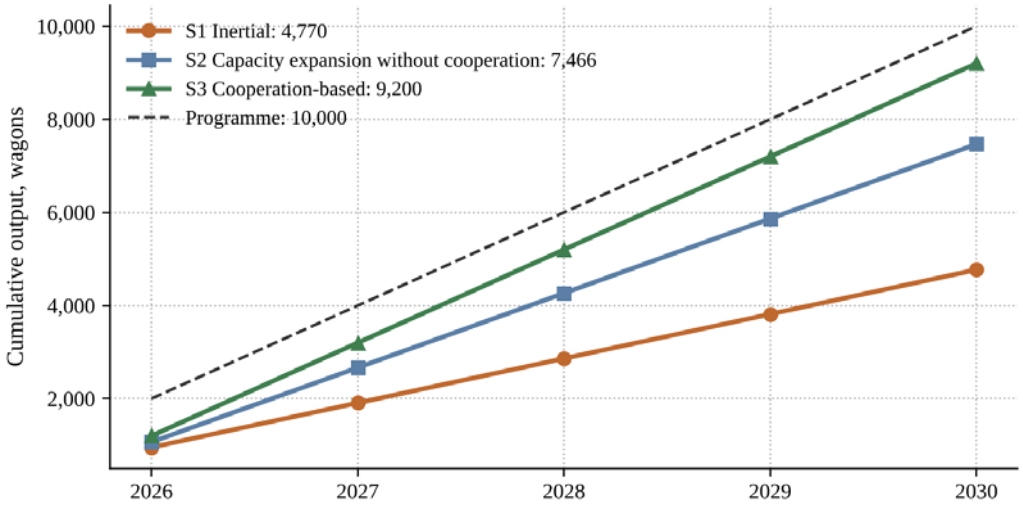


Figure 2. Cumulative freight wagon output by scenario and the programme volume[6]

Even the cooperation-based scenario achieves 92% of the programme: with full capacity utilisation from 2027, the 2026 shortfall is not offset. To achieve the programme volume, the model therefore points to the need for earlier commissioning of capacity, additional output on a cooperation basis (about 800 wagons over the period), or adjustment of programme deadlines in the goal-setting block — which is precisely the function of the feedback loop.

DISCUSSION

The scenario analysis confirms the main hypothesis of the model: the effect of capacity expansion (scenario S2 versus S1, an increase of 2,696 wagons) is substantially complemented by the effect of cooperation (S3 versus S2, a further 1,734 wagons), because cooperation acts on the constraints B_t and S_t, which cannot be addressed by expanding assembly alone. This is consistent with E. Goldratt's conclusions [16] and with the systems principle that the properties of a system cannot be reduced to those of its elements [7].

The novelty of the model lies in linking, within a single loop, the regulatory instruments of the 2026 Decree — guaranteed contracts, concessional loans and assessment of projects' contribution to cooperation [4] — with sectoral output constraints and certification requirements [22]. Unlike separate sectoral programmes, the model includes feedback: a deviation of actual results from the target in block 8 triggers a revision of the form of cooperation, support instruments or the targets themselves, implementing the PDCA cycle [10]. Limitations: utilisation parameters in the scenarios are assumptions, and the scenarios do not account for financial constraints; the model requires calibration using enterprise data on section capacity and component supply.

CONCLUSIONS AND RECOMMENDATIONS

1. An integrated methodological model of eight blocks (goal setting, diagnostics, cooperation design, economic justification, institutional support, implementation, assessment and monitoring) combined into a

5 Calculated by the author; scenario assumptions were set by the author based on official data [6; 5].
6 Calculated by the author (Table 3).

management cycle with feedback has been developed.

2. The core of the model — the condition that output is limited by the minimum of utilised assembly capacity, bottleneck throughput and component supply — formalises the dependence of output on these factors and substantiates the role of cooperation as a means of removing constraints.

3. Testing on official data showed that the programme of 10,000 freight wagons is 47.7% completed in the inertial scenario, 74.7% with capacity expansion without cooperation, and 92.0% in the cooperation-based scenario.

4. It is recommended to use the model as the methodological basis of a sectoral industrial cooperation programme in railway engineering, with annual monitoring of block 2 and block 7 indicators and a mechanism for adjusting programme deadlines and instruments.

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