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Project Management and Lean Manufacturing as the Basis of Operational Efficiency of Enterprises in the Mining and Metallurgical Industry

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Abstract: Under conditions of high price volatility in commodity markets, tightening environmental regulation, and chronic overcapacity, enterprises of the mining and metallurgical complex face the imperative not of incremental but of structural shifts in operational efficiency. In response to this challenge, the paper develops and theoretically substantiates an integrative framework that combines project management (PM) with lean manufacturing practices as complementary mechanisms of organizational development. The central proposition of the study is that sustainable operational excellence is achieved not by isolated Lean initiatives, but by their systematization and disciplined implementation within the contour of mature project procedures: from portfolio prioritization and stage-gate management to benefits control and the replication of best practices. Methodologically, the work draws on a systematic analysis of academic and industry literature, content analysis of managerial documentation, and case studies. In conclusion, it is argued that the synergy of PM and Lean, reinforced by digital transformation (sensors and MES/APS, analytics and predictive models, process mining), moves the enterprise from point improvements to systemic, reproducible changes in the operating model, with a direct effect on financial results and business resilience. The materials contained in the study will be of interest to senior executives and operations directors of the mining and metallurgical complex, as well as to researchers in industrial engineering and strategic management.

Keywords: operational efficiency, lean manufacturing, project management, mining and metallurgical industry, Toyota Production System, OEE, change management, digital transformation, case study, continuous improvement.

Introduction

The mining and metallurgical complex in 2024–2025 operates within a heterogeneous and multilayered market landscape, where global risks overlap with local windows of opportunity [1]. At the global level, structural imbalance is deepening: according to OECD estimates, by the end of 2024 excess steelmaking capacity will reach 602 million tons, that is, more than 30% of global steel output [3]. Taken together, this generates an efficiency paradox: maintaining margins and market position can no longer rely on extensive volume expansion; leadership in unit costs and operational performance becomes decisive.

The need to search for new configurations of operational excellence is reinforced by external pressures. First, high volatility in commodity and energy markets and persistent inflationary pressure continue, directly increasing the cost of metal products [4]. Forecast estimates for 2025 suggest a further rise in a number of positions, in particular aluminum by about 6.3% [3, 4]. Second, the regulatory and investment influence of the environmental, social, and corporate governance (ESG) agenda is intensifying: industry reviews qualify ESG simultaneously as a key risk and a source of opportunities, requiring a balance between production goals and sustainability commitments [2]. In this logic, operational efficiency ceases to be a purely financial category and becomes the core of a sustainable strategy. The philosophy of lean production, aimed at the systematic elimination of losses — excessive consumption of energy and materials, idle operations, and so forth — directly correlates with ESG objectives [8]. Consequently, the introduction of Lean approaches acts not as a private operational solution but as a practical mechanism for implementing a company's ESG strategy.

The scientific problem lies in the gap between the research bodies on lean production [10] and project management [12] as applied to the mining and metallurgical complex: these areas are more often treated as autonomous disciplines. The literature lacks an integrated, holistic model in which project management would perform the role of a governing framework for deploying the principles of Lean in the form of a portfolio of strategic initiatives adapted to the capital-intensive and often continuous production flows of heavy industry [14].

The aim of the study is to develop and theoretically substantiate a synergistic model in which project management methodologies provide a structural platform for the effective implementation of adapted principles of lean production aimed at achieving sustainable operational excellence of enterprises in the mining and metallurgical complex.

The author's hypothesis is that sustainable growth of operational efficiency in the mining and metallurgical complex sector is determined not by the episodic application of individual Lean tools but by their institutionalization as a portfolio of strategic projects managed by mature project management practices and accelerated by digital transformation.

The scientific novelty is determined by the conceptualization of an integrated Project Management — Lean Production framework that systematically links strategic project management with a toolkit of operational improvement specifically tuned to the technological, economic, and organizational constraints of the mining and metallurgical industry.

Materials and Methods

The study relies on a qualitative, synthetic research strategy aimed at constructing and testing a conceptual model through the comparison and integration of heterogeneous data. The methodological architecture comprises three mutually reinforcing components: a systematic literature review, the case-study method, and content analysis of corporate materials. This configuration ensures methodological triangulation and enables the combination of theoretical rigor with practice-oriented validation of the results.

The systematic review constitutes the foundational framework of the study and covers two complementary bodies: academic and industry. It includes peer-reviewed publications along target search trajectories that integrate production system theory and lean manufacturing, the specifics of their adaptation to metallurgy and the mining sector, the application of the overall equipment effectiveness (OEE) metric, as well as approaches to project management in capital-intensive industries. The inclusion criteria provided for thematic relevance, scientific novelty, and sufficient methodological transparency. Industry analytical reports of leading firms (McKinsey & Company, Deloitte, EY) for 2024–2025 were used to calibrate the theoretical conclusions against up-to-date material, to identify dominant trends, risks, and strategic imperatives, thereby grounding the model in the contemporary context and expanding the spectrum of observed practices.

The case-study method was employed for empirical verification of the proposed synergistic model and for elucidating the mechanisms of its operationalization. Case selection was carried out according to three criteria: the global significance of the company and its role in the target markets; the presence of a publicly articulated agenda for improving operational efficiency; the availability of detailed sources (annual reports, strategic presentations, press releases) documenting the course of transformations.

Content analysis performed an auxiliary but critically important function of systematizing the corpus of corporate documentation. A coding scheme was developed to identify and group strategic priorities, implemented initiatives, target benchmarks, and reporting indicators related to operational efficiency, project management practices, and the implementation of lean manufacturing principles.

Results and Discussion

The intellectual core of the philosophy of lean production is the Toyota Production System (TPS), which took shape in the mid-20th century [8]. TPS should be understood not as a set of tools for improvement but as an integrated production and management architecture aimed at the sustainable creation of customer value through the continuous identification and elimination of sources of waste at all levels of the organization [8].

The key to this architecture is the triad of systemic dysfunctions: muda, mura, and muri [19]. Muda captures all activities that consume resources without adding value for the customer; mura describes unevenness and variability of operations that provoke breakdowns, queues, and unplanned downtime; muri reflects the overburdening of people and equipment, leading to accelerated wear, errors, and safety risks. In the classical interpretation, muda is specified by eight types: overproduction, waiting, unnecessary transportation, overprocessing, excess inventory, unnecessary motion, defects, and unused employee creativity [8]. The interrelation of the triad is fundamental: mura gives rise to muri, and their combination crystallizes into muda — therefore, combating waste requires simultaneous flow leveling and reduction of overburden, rather than local optimization of isolated areas.

The central mechanism of TPS is Kaizen — an institutionalized practice of continuous small improvements that involves all levels of personnel, from operators to managers. Kaizen establishes a discipline of observing the process, experimenting, and standardizing achieved improvements, thereby turning improvements from one-off projects into the routine of everyday work [20].

At the same time, the direct copying of solutions developed for discrete automotive manufacturing into the context of heavy industry proves methodologically incorrect. Mining and metallurgical enterprises are characterized by high capital intensity of assets, long technological cycles, strict operating constraints, and often a continuous nature of processes (a telling example is blast-furnace smelting). These features require an adaptive interpretation of Lean tools, a rethinking of metrics, and a different logic of flow balancing [10].

An analytical examination showed that the suitability of key Lean approaches depends on the specific production stage. The 5S method (Sort, Set in order, Shine, Standardize, Sustain) and the cultural platform of Kaizen have broad transferability: they establish operational hygiene — visual management, standard discipline, and sustained employee engagement in the search for improvements — and are therefore effective across the entire value chain of the mining and metallurgical complex without significant limitations [10].

Total Productive Maintenance (TPM) tools, by contrast, demonstrate uneven effectiveness. In continuous units such as blast furnaces, the scope for autonomous maintenance and planned shutdowns is extremely limited; however, at subsequent stages — in foundry, rolling, and mechanical assembly shops — TPM reveals its potential. Delegating part of the scheduled equipment care and primary diagnostics to operators reduces unplanned downtime, increases capacity readiness, and establishes feedback between the actual condition of the machine and maintenance planning [10].

The Single-Minute Exchange of Die (SMED) methodology is most effective where the product range is wide and changeovers are frequent: on rolling mills, press, and stamping equipment. Systematic separation of internal and external operations, architectural unification of tooling, and standardization of sequences make it possible to reduce changeover time from hours to minutes, which is critical for increasing flexibility, reducing batch sizes, and leveling the flow without accumulating buffer inventories [10].

To visualize the conclusions and to support managerial decisions on the selection of tools, an applicability matrix of Lean instruments was developed across production stages and process types (see Table 1).

Table 1. Applicability matrix of lean tools in metallurgical processes [10]

Lean tool	Mining and beneficiation	Smelting (continuous process)	Rolling and casting (discrete-continuous)	Final processing
5S	High	High	High	High
Justification	Workplace organization, safety, visual management.	Standardization of work areas, risk reduction, cleanliness.	Organization of tooling storage, zone marking.	Order at workplaces, standardization of operations.
Kaizen	High	High	High	High
Justification	Engaging personnel in improving mining and haulage processes.	Identification and elimination of minor losses in energy consumption and logistics.	Improvement of setup processes, reduction of defects.	Optimization of manual operations, improved ergonomics.
TPM	Medium	Limited	High	High
Justification	Autonomous maintenance of mobile equipment and conveyors.	Applicable to auxiliary equipment but not to the main unit.	Key tool for increasing reliability of rolling mills and presses.	Operator-driven maintenance of machine tools and machining centers.
SMED	Low	Low	High	Medium
Justification	Processes do not involve frequent changeovers.	Continuous process without changeovers.	Critically important for reducing roll and die change time.	Reducing tool change time on machine tools.

The key indicator for quantitative assessment of the effectiveness of lean initiatives—and above all TPM programs—is Overall Equipment Effectiveness (OEE). By definition, OEE is a multiplicative composition of three components: availability (the share of calendar time during which the equipment is in an operable condition), performance (the ratio of the actual output rate to the nominal one), and quality (the proportion of conforming product) [20]. The multiplicative nature of the metric is fundamentally important: it does not permit compensation of one type of loss by another and thereby increases diagnostic sensitivity to local disruptions, from downtimes and microstoppages to speed losses and defects. At the empirical level this is corroborated by industry cases: for example, a metalworking enterprise in Peru, having sequentially implemented a bundle of lean tools (5S, SMED, TPM), increased OEE from 68,5% to almost the industry-wide benchmark of ≈85% [20]. Consequently, OEE functions not only as a gauge but also as a managerial lever that enables ranking of loss sources and focusing improvement efforts where the gain in cumulative efficiency is maximal.

The implementation of lean production is not a one-off campaign but a multistage program of organizational change that requires formalized transformation management. Characteristic failures arise when companies introduce tools piecemeal, ignoring cultural preconditions, process architecture, and the project management system, that is, acting without an integrated plan and feedback mechanisms. Here the discipline of project management (PM) plays a key role, providing the methodological framework from initiation and stakeholder management to metrics, risks, and staged control. At the same time, PM maturity in the mining and metallurgical sector remains on average insufficient: a study of a South African mining company recorded an average maturity of 2,92 out of 5 on a five-level model, corresponding to the Defined level, in which standards formally exist but are not yet integrated and are weakly grounded in quantitative data [12]. The maturity profile is heterogeneous: relatively strong areas are procurement management (3,21) and risk management (3,10), reflecting the specifics of a capital-intensive and high-risk industry, whereas the most vulnerable remain human resource management (2,46) and project scope management (2,79) [12]. From a practical standpoint, this means that the already developed risk management practices should be purposefully used as a support mechanism to reduce the uncertainty of transformation initiatives for Lean implementation, while simultaneously building competencies in scope and people management, the two domains that are critically important for a sustainable lean transformation.

Project management forms a rigid organizational framework for Lean transformation, aligning lean manufacturing initiatives with the standardized PMBOK process groups and eliminating ad hoc implementation.

Regarding initiation and planning, measurable objectives and project boundaries are formulated at the start (for example: increase the rolling mill OEE by 15% within 12 months), the initial comparison baseline is established, and a work breakdown structure (WBS), resource model, and a project network schedule with milestones are built. The key analytical tool is value stream mapping (VSM): it reveals types of waste, bottlenecks, and variability, and also makes it possible to design the future state of the stream and to form a prioritized register of improvements with estimates of effect and effort. At this stage the project team is assembled and roles are distributed, which ensures manageability of cross-functional interactions.

Regarding execution and control, plan implementation unfolds through focused Kaizen sessions, the deployment of 5S, TPM, standardized work, rapid changeover, and other Lean mechanisms. Progress is tracked within a unified system of indicators: in addition to the target OEE, leading and lagging KPIs are maintained, as are visual management panels (obeya, daily standups). Deviations from the schedule and target values are recorded by management control tools (up to and including methodologies such as earned value analysis), followed by the launch of corrective actions in the PDCA logic.

Proactive work with uncertainty includes maintaining a risk register with probability and impact assessments, response plans, and escalation triggers. A separate track is stakeholder management: stakeholder mapping, regular communications according to the approved plan, capability development, and reduction of resistance to change at all levels from top management to production shifts. A telling antipattern is the Minas-Rio megaproject in Brazil: large-scale schedule and budget overruns demonstrate what underestimation of formalized project management practices leads to, primarily in stakeholder management and risk assessment.

The conceptual model (see Fig. 1) shows how VSM and the formation of the future state dominate at the initiation/planning stage; Kaizen, 5S, and TPM are the core of execution; visual management, metrics boards, and OEE control are the basis of monitoring; and the standardization of best practices and lessons learned consolidate the effect at closure, preventing rollback and ensuring the sustainability of transformations. Such end-to-end alignment of Lean methods with PMBOK processes moves the transformation from one-off initiatives to a disciplined change program governed by objectives, data, and risks.

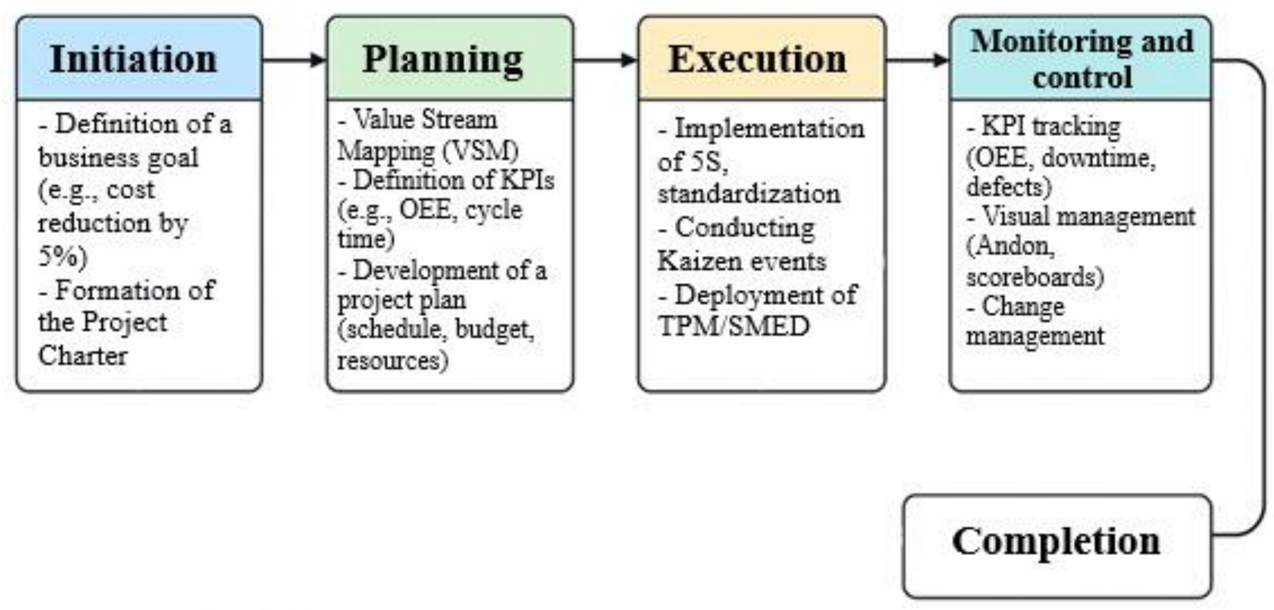

Fig. 1. Conceptual model of integrating Lean tools into the project life cycle (PMBOK) (compiled by the author based on []).

The proposed logic clearly shows: Lean and project management do not compete but methodologically complement each other. Project management acts as an operating system for purposeful change — it sets the architecture, cadence, and control mechanisms; Lean fills this architecture with content — specific methods, tools, and effect metrics. Together they form a managed improvement cycle: from initiation and planning to sustained standardization and scaling of solutions at the organizational level.

Synergy is especially evident where the transformation is built as a portfolio of projects with clear prioritization and common execution standards. The experience of Rio Tinto is illustrative. The restructuring announced in 2025 is not an administrative regrouping but a large-scale project intervention aimed at operational excellence. The consolidation of assets into three product verticals (Iron Ore; Aluminium and Lithium; Copper) project-wise institutionalizes the standardization of end-to-end processes, accelerates the exchange of best practices, and creates a unified contour for implementing systemic initiatives, including the Safe Production System [6, 11]. Such a design at the corporate level forms an organizational framework in which Lean principles are implemented consistently and continuously, overcoming the fragmentation of business units and the locality of effects.

Long-term operational excellence programs do not evolve linearly but through stages of maturity building — in the logic described by the McKinsey model: a transition from local improvements to integrated flows, then to end-to-end production systems, and finally to a sustained corporate culture of continuous improvement. This trajectory underscores that the synthesis of Lean and project management is not a one-off initiative but a reproducible organizational capability [16, 17].

The trajectory set by this model has a pronounced phase logic: at the initial stage of the transformation, a stepwise increase in output is recorded — up to 40% in total over the first three years; then the dynamics switch to a mode of moderate but stable productivity growth of 3–5% annually, accompanied by a simultaneous reduction in unit costs by 3–6% per year. The key — and in the long-term horizon defining — effect is the consistent increase in employee engagement by 5–10 percentage points per year, forming an anchor for the sustainability of the achieved improvements [4].

For managerial coordination and the correct evaluation of such a multilevel program, a balanced KPI system is required that integrates PM and Lean tools and reflects their composite effect — from performance and operational resilience to behavioral shifts in the organization (see Table 2).

Table 2. Key Performance Indicators (KPI) for assessing the synergistic effect from implementing Lean and PM

[4, 7, 9, 13]

Category	KPI	Description	Relation to Lean / PM
Financial	Reduction in unit cost per unit of output	Reflects overall efficiency improvement and waste reduction.	Lean: Elimination of the 8 types of waste. PM: Achievement of the project's financial objectives.
Financial	Return on investment (ROI) for improvement projects	Evaluation of the economic feasibility of transformation initiatives.	PM: Justification and evaluation of project success.
Operational	Overall equipment effectiveness (OEE)	Composite indicator of availability, performance, and quality.	Lean: Core metric for TPM and operational improvements.
Operational	Production cycle time (Lead Time)	Time from the start to the end of the process; reducing it increases flexibility.	Lean: Outcome of eliminating waiting and other wastes.
Project	% of projects completed on time and within budget	An indicator of the maturity and effectiveness of project management processes.	PM: A basic indicator of project management success.
Project	Level of achievement of project objectives (Benefit Realization)	Assessment of the extent to which the benefits stated in the Project Charter have been achieved.	PM: Focus on value creation rather than mere task completion.
Human resources	Employee retention rate (Retention Rate)	A high value indicates a healthy culture and engagement.	Lean/PM: Result of engaging employees in improvements and clear work organization.
Human resources	Number of submitted and implemented improvement proposals	A direct indicator of activity and Kaizen culture.	Lean: A metric of engagement in continuous improvement.

Despite the significant potential of the integrated PM–Lean model to enhance operational efficiency and the manageability of change, its practical implementation is associated with systemic difficulties. The most stringent barrier is entrenched resistance to change as a consequence of historically established norms and practices. In production teams, Lean is often interpreted as a euphemism for downsizing, which fuels a deficit of trust and defensive behavior among personnel. Asymmetry of communications between management and levels leads to distortion of meanings and the substitution of goals by instrumental routine. Without purposeful retuning of symbolic frames (a shared language of value, safety, and respect), mechanisms of two-way feedback, and fair rules of participation, any instrumental innovations are doomed to formalization and the subsequent degradation of effects.

This is also due to the fact that MMC enterprises operate within extended, technologically interdependent chains with high capital intensity and long equipment life cycles [14]. Inherited island automation, heterogeneous IT landscapes, and obsolete interfaces create gaps in data and processes. In the absence of a unified target digitalization architecture and an end-to-end data model, production initiatives degenerate into patchwork solutions that do not provide a cumulative systemic effect [5]. Integration risks manifest themselves in inconsistency of master data, conflict between local and global metrics, an increase in transaction costs for synchronization, and difficulties in scaling pilots.

Successful transformation requires T-shaped profiles: a combination of depth in Lean tools (VSM, standardization, visual management, quick changeover) with managerial literacy across the project cycle (portfolio, stage-gate model, risk and stakeholder management) and a basic analytical culture (data, cause-and-effect analysis, visualization, interpretation of deviations). In practice, gaps are revealed both among managers (in prioritization and dependency management) and among foremen/engineers (in problem-solving skills and working with data), which provokes dependence on external consultants and learned helplessness within the organization.

For a clear explication of the strategic implementation landscape, it is advisable to use a SWOT analysis (Fig. 2), linking strengths (for example, maturity of production discipline) and opportunities (digital platforms, end-to-end analytics) with internal vulnerabilities (cultural and competency gaps) and external threats (market volatility, regulatory burden). Such a frame facilitates the development of a prioritized roadmap: the sequence of integration steps, a package of measures for competence development, the tuning of metrics and mechanisms of personnel participation, with a clear delineation of areas of responsibility and criteria for success.

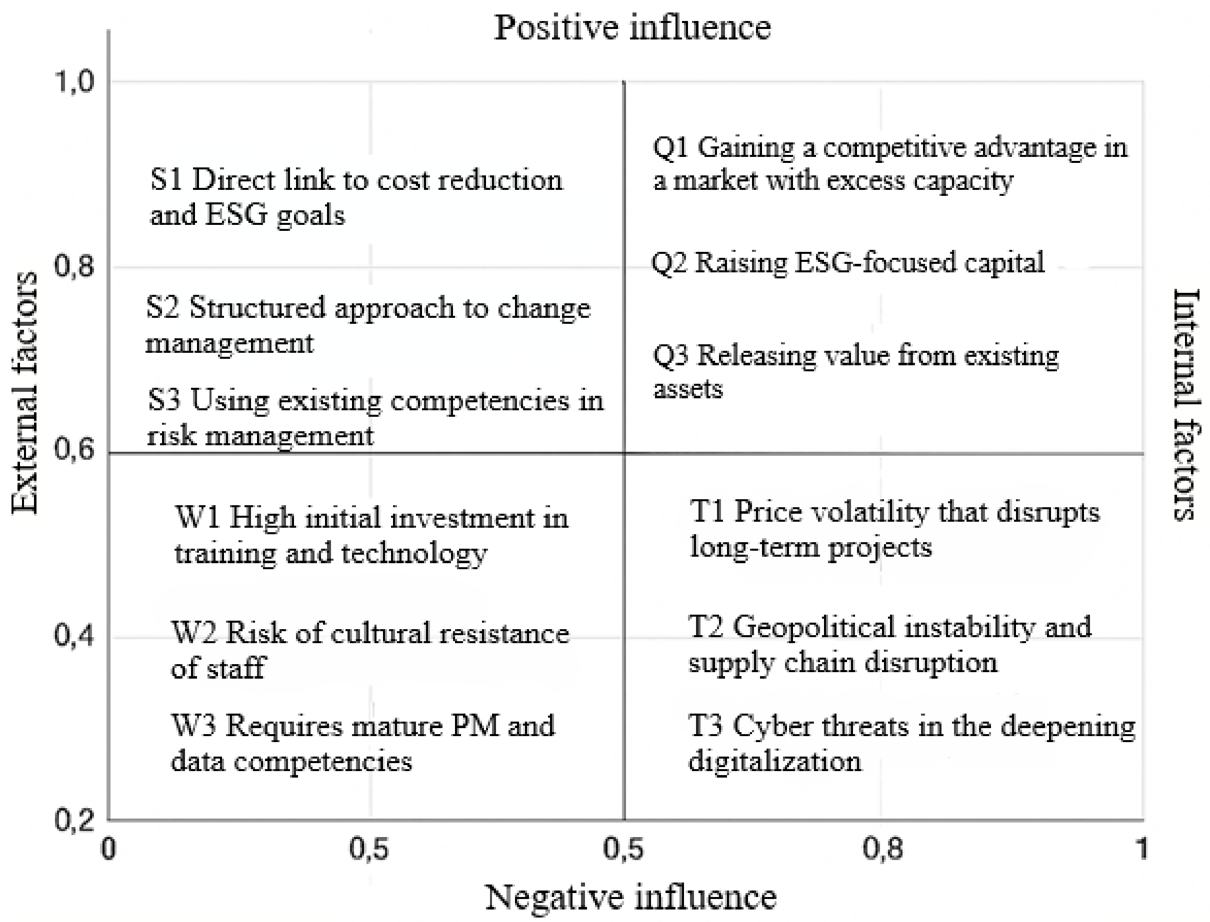

Fig. 2. SWOT analysis of the implementation of the integrated PM-Lean model in the mining and metallurgical complex (compiled by the author based on [5, 15, 18]).

The critical success factors for implementing an integrated PM–Lean model are best viewed as an interconnected sociotechnical loop, in which executive sponsorship, digital infrastructure, and people development form a self-sustaining improvement loop. The most powerful predictor of success is not declarative but active support: the personal role of the top leader in removing organizational bottlenecks, regular Gemba visits, resource prioritization, and protected windows for experiments. The key is the institutionalization of accountability through a clear cascade of metrics (from strategic objectives down to shift takt time), mentoring of project teams, and managerial resolution of conflicts between local and system-level objectives. Such sponsorship reduces the transaction costs of coordination and increases the throughput of change.

Contemporary Lean practices are inconceivable without end-to-end digital enablement: industrial IoT and MES/ERP integration provide a continuous stream of loss data, while the analytics loop—from operational visualization to cause-and-effect analysis—makes it possible to rapidly localize sources of variability. New technologies, including generative artificial intelligence, are viewed by industry leaders as the next step that accelerates solution discovery, knowledge standardization, and the maintenance of execution discipline [1].

This drive toward digitalization is manifested in the creation of a comprehensive digital framework within mining and metallurgical companies. Large mineral resource operators, after implementing the Lean production methodology, seek to mitigate risks by building a digital twin of production capacities. The architecture of such a system is based on integrating diverse data sources — from field equipment sensors to corporate accounting systems — into a unified corporate data warehouse. This warehouse, in turn, provides an analytics platform for monitoring project activities and, most importantly, a platform for predictive modeling. The primary function of this digital infrastructure is the automation and objectivization of deviation management at all stages of the production process. Owing to a system of information dashboards and established monitoring points, it enables daily analysis of deviations from target indicators, which allows for timely corrective actions and the identification of critical issues before they affect project outcomes. Although digital technologies are not a panacea for all problems, they are an important aspect of building a modern, sustainable operational production management system that relies equally on standardization, project management discipline, and a culture of continuous improvement.

Thus, in the current economic and geopolitical context, a high level of operational efficiency is not an option but a necessary condition for the long-term competitiveness of mining and metallurgical enterprises. Sustainable results are achieved not through eclectic adoption of fashionable management practices, but through the design and consistent execution of a coherent, integrated architecture of change in which local initiatives are subordinated to a unified logic of value and risk management.

Conclusion

The conceptual model proposed within the study and its accompanying toolkit (applicability matrix, KPI dashboard, SWOT analysis) address the full cycle of improvement management: from the selection of initiatives—to their project orchestration and control of effects. For executives and operations managers of the ГМК this enables a shift from the question of what to do (implement Lean) to the question of how exactly to do it (manage the implementation as a portfolio of projects with a clear logic of goals, assumptions, risks, and metrics). Such a shift increases the likelihood of sustainably consolidating operational benefits and prevents rollback after the completion of individual initiatives.

The results obtained substantiate the need to move from instrumental eclecticism to architectural thinking about operational improvements: efficiency arises where the Lean approach is embedded in a managed project-portfolio system that relies on digital infrastructure and is supported by a culture of continuous improvement.

References

1. Deloitte. (2024). Tracking the trends 2024: The top 10 trends facing the mining and metals sector [Electronic resource]. - Access mode: https://www.deloitte.com/ua/en/Industries/mining-metals/about/tracking-the-trends.html (date of access: 08.07.2025).
2. Top 10 business risks and opportunities for mining and metals in 2024. Ernst & Young [Electronic resource]. - Access mode: https://www.ey.com/content/dam/ey-unified-site/ey-com/en-gl/insights/energy-resources/documents/ey-top-10-business-risks-and-opportunities-for-mining-and-metals-in-2024-final.pdf (date of access: 08.07.2025).
3. Concentrating on the future [Electronic resource]. - Access mode: https://www.pwc.com/id/mine-2025 (date of access: 08.08.2025).
4. Mining for operational excellence [Electronic

resource]. - Access mode:https://www.mckinsey.com/capabilities/operations/our-insights/mining-for-operational-excellence (date of access: 10.07.2025).

5. Top 10 business risks and opportunities for mining and metals in 2024 [Electronic resource]. - Access mode: https://www.ey.com/en_ps/insights/energy-resources/risks-opportunities (date of access: 12.07.2025).

6. Top 10 business risks and opportunities for mining and metals in 2024 [Electronic resource]. - Access mode: https://www.miningsee.eu/top-10-business-risks-and-opportunities-for-mining-and-metals-in-2024/ (date of access: 14.07.2025).

7. Pishchalkina I., Pishchalkin D., Suloeva S. Research of the efficiency of mining and metallurgical enterprises based on the environmental, social, and governance risk rating in the context of digital transformation //A: A. – 2022. – Vol. 5. https://doi.org/10.14716/ijtech.v13i7.6181.

8. Toyota Production System [Electronic resource]. - Access mode: https://global.toyota/en/company/vision-and-philosophy/production-system/ (date of access: 15.07.2025).

9. Wojtkowiak D., Cyplik P. Operational excellence within sustainable development concept-systematic literature review //Sustainability. – 2020. – Vol. 12 (19). https://doi.org/10.3390/su12197933.

10. Kubica S. et al. The principles of lean manufacturing in metallurgical processes //apresentado na METAL. – 2015. – pp. 1994-1999.

11. Ade M., Deshpande V. S. Lean manufacturing and productivity improvement in coal mining industry //International Journal of Engineering Research and Development. – 2012. – Vol. 2 (10). – pp. 35-43.

12. Nhlengethwa N., van der Lingen E. Case study on project management at a mineral sand organization //Proceedings of PICMET'14 Conference: Portland International Center for Management of Engineering and Technology; Infrastructure and Service Integration. – IEEE, 2014. – pp. 2524-2529.

13. Nelwamondo P., Pretorius J. H. C. Application of the event chain project management methodology to a mining stope //Journal of the Southern African Institute of Mining and Metallurgy. – 2018. – Vol. 118 (12). – pp. 1233-1242. https://doi.org/10.17159/2411-9717/2018/v118n12a1.

14. Gajdzik B., Grabowska S., Saniuk S. A theoretical framework for industry 4.0 and its implementation with selected practical schedules //Energies. – 2021. – Vol. 14 (4). https://doi.org/10.3390/en14040940.

15. Małysa T. et al. Application of Selected Lean Manufacturing Tools to Improve Work Safety in the Construction Industry //Applied Sciences (2076-3417). – 2024. – Vol. 14 (14). https://doi.org/10.3390/app14146312.

16. Kumar S. et al. Role of Lean Six Sigma in manufacturing setting: a systematic literature review and agenda for future research //The TQM Journal. – 2024. – Vol. 36 (7). – pp. 1996-2047. https://doi.org/10.1108/TQM-12-2022-0338.

17. Xiao Y. et al. Exploring green mining research trends through web of science: A bibliometric analysis based on VOSviewer and CiteSpace //Sustainable Environment. – 2025. – Vol. 11 (1). - pp.1-5.

18. Emere C. et al. Harnessing Emerging Technologies in the Global Mining Sector from a Bibliometric Standpoint //Mining. – 2025. – Vol. 5 (1). - pp. 1-3. https://doi.org/10.3390/mining5010013.

19. Akhtar W., Ansari A. the Implementation of Toyota Production System (TPS) in Indian MSMEs: a Study on the Motive, Barriers, Challenges, Success Factor and Applications //Int'l J of Engineering Applied Sciences and Technology. – 2020. – Vol. 4 (12). – pp. 102-111. https://doi.org/10.33564/IJEAST.2020.V04I12.013.

20. Quiroz-Flores J. C., Collao-Díaz M. F. Production model using Lean Manufacturing tools applied in a continuous production line of a Peruvian metalworking company //2022 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI). – IEEE, 2022. – pp. 1-4.