International Journal of Engineering& Scientific Research
Vol.14 Issue 08, August 2026
ISSN: 2347-6532 Impact Factor: 8.076
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Post-Project Analysis as a Tool for Improving the Production of Non-Standard Metal Structures

Yuriy Kanalin

Abstract

The article examines post-project analysis as a tool for improving the production of non-standard metal structures. It substantiates that, under conditions of custom and low-volume production, project completion should not be limited to final quality control or handover of the work to the customer. A completed order should be viewed as a source of managerial information that makes it possible to identify the causes of deviations, recurring errors, time losses, material overruns, and problems at the stages of fabrication, logistics, and installation.

A practice-oriented methodology for post-project analysis is proposed. It includes collecting factual data after project handover, classifying deviations by stages of the production-and-installation cycle, identifying the causes of problems, and developing corrective actions for subsequent orders. Special attention is given to such tools as a post-project order card, a register of typical errors and recurring deviations, and a system of indicators for evaluating project results.

The practical significance of the proposed approach lies in its applicability to enterprises that manufacture non-standard metal structures, advertising structures, architectural metal elements, stainless-steel products, and structures for commercial, warehouse, or industrial facilities. The use of post-project analysis makes it possible to reduce the recurrence of the same errors, decrease downtime and rework, improve the quality of the technical specification, design documentation, material preparation, and installation preparation, and develop the enterprise's internal production standards based on the results of completed projects.

.

Keywords:

post-project analysis;
non-standard metal structures;
production-and-installation cycle;
custom production;
design documentation;
technical specification;
material preparation;
production deviations;
corrective actions;
internal production standards.

Author correspondence:

Yuriy Kanalin,
Email: yuriikanalin@gmail.com

1. Introduction

Modern production of non-standard metal structures requires not only high-quality execution of technological operations, but also systematic improvement of the entire production-and-installation process [1]. Each custom project has its own technical, structural, material, and installation-specific features. Therefore, enterprises often face incomplete initial data, changes in drawings, delays in material supply, rework in the workshop, incomplete kitting before installation, or additional site visits by the installation team [2].

The relevance of the problem lies in the fact that a significant share of production losses becomes fully clear only after the project has been completed. During order execution, the main focus is usually on the operational resolution of current tasks; however, after the work has been handed over, a systematic analysis of the causes of deviations is not always carried out [11]. As a result, the same errors may recur, while accumulated production experience is not transformed into internal rules, standards, or corrective actions [12]. In contemporary research, the lessons-learned system is viewed as a tool of organizational knowledge management that ensures the collection, preservation, and reuse of experience from completed projects [17].

The research problem lies in the fact that, under conditions of custom and low-volume production of non-standard metal structures, errors often have a recurring character but remain insufficiently formalized. If several consecutive projects are delayed because of incomplete initial data, inaccurate drawings, untimely material preparation, or missing components before installation, this indicates not only individual execution errors, but also weak points in the organization of the process. It is post-project analysis that makes it possible to identify such patterns and transform individual comments into a system of managerial decisions [11].

The purpose of the article is to develop and substantiate a practice-oriented approach to using post-project analysis as a tool for improving the production of non-standard metal structures. This approach is aimed at identifying the causes of deviations, reducing recurring errors, decreasing downtime and rework, improving the quality of preparation for future orders, and forming the enterprise's internal production standards.

To achieve this purpose, the following tasks are planned:

1. Determine the essence of post-project analysis and its role in the production of non-standard metal structures.
2. Substantiate the difference between post-project analysis and final quality control.
3. Identify typical problems that become apparent after completion of a production-and-installation project.
4. Propose a methodology for conducting post-project analysis of completed orders.
5. Develop an approach to classifying deviations by stages of the production-and-installation cycle.
6. Define tools for recording the results of the analysis: a post-project card, a register of typical errors, a cause-and-effect matrix, and a log of changes and comments.
7. Substantiate indicators for evaluating the effectiveness of post-project analysis.
8. Show how the results of the analysis can be used to improve subsequent orders.

The object of the research is the process of fabricating and installing non-standard metal structures within custom and low-volume production-and-installation projects.

The subject of the research is the organizational and managerial tools of post-project analysis that make it possible to identify the causes of production and installation deviations, systematize accumulated experience, and use it to improve future orders.

The methodological basis of the article consists of a process-based approach, analysis of completed production-and-installation projects, cause-and-effect analysis of deviations, comparison of planned and actual indicators, classification of typical errors by process stage, and assessment of timelines, quality, downtime, rework, installation comments, and cost [3]. Contemporary studies on root-cause analysis in industrial production emphasize the need to distinguish the external manifestation of a defect from its root cause [22].

The scientific novelty of the article lies in the development of a closed-loop process model of post-project analysis for the production of non-standard metal structures. This model combines the recording of actual deviations, classification by stages of the production-and-installation cycle, cause-and-effect analysis, development of corrective actions, and updating of the enterprise's internal production standards.

The practical significance of the proposed approach lies in its applicability to enterprises that manufacture non-standard metal structures, advertising structures, architectural metal elements, stainless-steel products, and structures for commercial, warehouse, or industrial facilities. The use of post-project analysis makes it possible to reduce the recurrence of the same errors, improve the quality of the technical specification and design documentation, enhance material and installation preparation, and ensure more predictable execution of subsequent projects.

Thus, post-project analysis should be considered a tool for continuous improvement in the production of non-standard metal structures [1]. Its value lies not only in recording the shortcomings of a completed project, but also in creating a system through which the enterprise learns from its own production experience.

1. Theoretical and Applied Foundations of Post-Project Analysis in the Production of Non-Standard Metal Structures

The production of non-standard metal structures has a distinctly project-oriented character [2]. Unlike serial manufacturing of typical products, where the main structural parameters, technological route, and material base are standardized in advance, in the field of custom metal structures each order is, in effect, a separate production-and-installation project [14]. This logic corresponds to the specific features of custom manufacturing, in which engineering, material preparation, and production planning are largely formed for a specific order [20]. Each project has its own initial data, individual drawings, material specification, structural joints, fabrication sequence, transportation logic, and installation conditions.

Under such conditions, the quality of the final result depends not only on the professionalism of individual performers or the technical capabilities of the workshop. The enterprise's ability to accumulate information about completed projects, analyze the causes of deviations, and use these conclusions to improve subsequent orders is of decisive importance [11].

1.1. Specific Features of Non-Standard Metal Structure Production as a Project-Oriented Process

Non-standard metal structures are created for a specific technical specification, site, and operating conditions [5]. These may include advertising structures, façade elements, architectural metal products, frames, stainless-steel products, and structures for commercial, warehouse, or industrial facilities. Even products that appear similar externally may differ significantly in dimensions, materials, fastening methods, coating, appearance requirements, and installation conditions.

The project-oriented nature of such production is reflected in the fact that each order passes through a full cycle of preparation and implementation: formulation of the technical specification, development of design documentation, material preparation, launch into the workshop, fabrication, quality control, kitting, delivery, installation, and handover of completed work [2].

The specific feature of non-standard production is that a significant share of decisions cannot be fully unified in advance. For one order, a complex fastening joint may be critical; for another, the precision of surface finishing; for a third, transportation dimensions or access to the installation site. Therefore, the enterprise should operate not according to the logic of repeating a single product, but according to the logic of controlled passage of each project through defined stages.

Design documentation occupies an important place in this process. For a non-standard metal structure, a drawing cannot be merely a graphic representation of the product. It must take into account the actual fabrication sequence: cutting, welding, assembly, grinding, painting or other finishing, packaging, transportation, and installation [5]. If the drawing does not account for workshop or installation logic, the problem often becomes apparent during execution: clarifications, rework, changes to joints, or additional time costs arise [14].

Material preparation is no less important. Materials are often selected for a specific order: different types of profiles, sheet metal, stainless steel, fasteners, decorative elements, paints, consumables, or components. The absence of even one critical element may delay workshop operations, change the fabrication schedule, or postpone installation [15].

Installation is also an integral part of project-oriented production. For many non-standard structures, completion of work in the workshop does not yet mean completion of the project. The product must be delivered, properly unloaded, installed, fastened, checked for compliance with the technical specification, and handed over to the customer. If installation conditions are not taken into account during design or kitting, errors may become apparent only on site, where correcting them is significantly more difficult and costly [16].

Project Element	**Manifestation in the Production of Non-Standard Metal Structures**
Individual technical specification	Each order has its own requirements for dimensions, materials, coating, installation, and deadlines
Separate design documentation	Drawings, specifications, and joints are adapted to the specific product
Non-standard structural solutions	Individual fastening joints, connections, modules, decorative elements, or façade elements may be required
Project-specific material preparation	Metal, fasteners, components, and coatings are purchased or reserved for a specific order

Production route	The sequence of operations depends on the complexity of the structure, materials, and finishing requirements
Installation logic	The project must take into account site access, installation method, fastening, equipment, and completeness
Post-project conclusion	Execution results are used to improve subsequent orders

Source: Compiled by the author.

Thus, a non-standard metal structure is not merely a product, but the result of an integrated production-and-installation project. For this reason, analysis of completed work makes it possible to identify which decisions were effective, which stages caused delays, where rework occurred, which material or installation issues were not taken into account, and what needs to be changed in the organization of subsequent orders.

1.2. The Essence of Post-Project Analysis and Its Difference from Final Quality Control

Post-project analysis is the systematic study of a completed production-and-installation project in order to determine actual results, identify the causes of deviations, and develop corrective actions for future orders [11]. For complex projects, it is especially important not only to record the experience gained, but also to ensure its application in future decisions, since this stage determines the practical value of the lessons learned [18]. Its purpose is not merely to record whether the project was completed, but to answer how exactly it progressed: where delays occurred, why rework appeared, which materials or components were not prepared on time, whether comments arose during installation, and how these factors affected timelines, quality, and cost.

In the production of non-standard metal structures, post-project analysis is especially important because errors often recur not by chance, but because of imperfections in the process [12]. If several consecutive projects encounter problems with initial data, this indicates the need to strengthen the stage of accepting the technical specification. If rework occurs because of drawings, the procedure for approving design documentation should be reviewed. If the installation team regularly encounters missing fasteners or an inaccurate installation scheme, completeness control before shipment should be strengthened.

Post-project analysis differs from final quality control. Final quality control is aimed at verifying the finished product or completed work [8]. It answers the question: “Does the product meet the requirements?” At this stage, geometry, weld quality, coating, completeness, appearance, correctness of installation, and compliance with the technical specification are checked [6].

Post-project analysis has a broader purpose. It answers the question: “What needs to be changed in the process so that the next order is completed faster, at lower cost, and with fewer errors?” Its subject is not only the finished product, but the entire path of its creation: the technical specification, design, approval, material preparation, production operations, quality control, logistics, installation, and interaction among process participants [10].

Criterion	**Final Quality Control**	**Post-Project Analysis**
Main question	Does the product meet the requirements?	What needs to be changed in the process for the next order?
Object of review	Finished product or installed structure	The entire production-and-installation process
Time of implementation	Before handover or during handover of completed work	After project completion
Main focus	Quality, completeness, compliance with the technical specification	Causes of deviations, recurring errors, loss of time and resources
Type of result	Accepted / requires rework / does not meet requirements	Conclusions, corrective actions, changes to internal rules

Management value	Prevents the handover of a low-quality product	Prevents the recurrence of problems in future projects

Source: Compiled by the author.

Final quality control is necessary, but it does not always explain why a problem occurred. For example, if a coating defect is identified during handover, quality control may record the need for rework [8]. However, post-project analysis must determine the actual cause: insufficient surface preparation, rushed painting, violation of the technological process, an uncoordinated drying schedule, damage during transportation, or the absence of an intermediate inspection before shipment [11].

Similar logic applies to installation. If missing fasteners are identified on site, final quality control can only record the fact of incompleteness [8]. Post-project analysis must determine why this happened: whether there was no completeness checklist, the responsible workshop supervisor failed to check the installation kit, changes in the joints were not communicated to the warehouse, or the installation scheme was not updated after approval [9].

Thus, post-project analysis does not duplicate final quality control; rather, it is a separate management tool. Its purpose is to ensure the accumulation of production experience, reduce the recurrence of errors, and form more stable rules for executing non-standard metal structure projects.

2. Typical Deviations in the Production-and-Installation Cycle

Post-project analysis has practical value when it is based not on general impressions of a completed project, but on specific deviations that occurred during its execution. In the production of non-standard metal structures, such deviations may include delays, rework, drawing changes, material shortages, fabrication defects, incomplete kitting, damage during transportation, or installation comments [4].

It is important to view deviations not merely as evidence of an error, but as a source of managerial information [11]. They show at which stage the process was insufficiently prepared, where information was lost, which decision was made too late, and what needs to be changed in subsequent orders.

Within the production-and-installation cycle, deviations should be divided into two groups: the first arises at the preparatory stages — during formulation of the technical specification, design, and material preparation; the second becomes apparent at the stages of fabrication, logistics, and installation [10].

2.1. Deviations at the Stages of Technical Specification, Design, and Material Preparation

The preparatory stages have a decisive influence on the entire subsequent cycle [14]. If the technical specification is incomplete, the drawings are insufficiently detailed, or materials are not prepared on time, these problems almost always carry over into the workshop, logistics, or installation stages [4]. At later stages, correcting them requires more time, resources, and additional coordination among process participants.

Deviations at the technical specification stage arise when insufficient initial data are collected at the start: precise dimensions, information about the installation site, type of fastening base, access conditions, coating requirements, transportation specifics, or acceptance criteria for the completed work [2]. Such shortcomings may seem minor at first, but later they lead to clarifications, delays in drawings, changes to the technical solution, or rework of elements that have already been fabricated.

Design-related deviations are associated with the quality of design documentation, the correctness of joints, dimensional accuracy, manufacturability of the structure, and consideration of installation logic [5]. Drawings for a non-standard metal structure must serve as a working tool not only for the designer, but also for the workshop, procurement, quality control, and the installation team [5].

Material preparation should be considered separately. If the specification is prepared late or inaccurately, production may face downtime due to the absence of metal, profiles, sheet material, paint, fasteners, or consumables [15].

Stage	Typical Deviation	Possible Consequences	What Post-Project Analysis Records
Technical specification	Incomplete measurements, unclear requirements, unknown installation conditions	Design delay, change in the technical solution	Which data were missing and when this was identified
Initial data	Absence of photos, site inspection, or information about the fastening base	Errors in joints, installation difficulties	Who was supposed to provide or verify these data
Design	Insufficient detailing of drawings, failure to account for manufacturability	Workshop stoppage, clarifications, rework	Which element of the design documentation was incomplete or incorrect
Approval	Changes after drawings were transferred to the workshop	Rework of parts, schedule shift	Reason for the change, date, responsible person, and impact on deadlines
Material preparation	Error in the specification or absence of material	Downtime, urgent purchases, cost overruns	Which material was critical and why it had not been prepared
Material substitution	Late or unapproved replacement of metal, fasteners, or coating	Quality risk, change in cost, work delay	Who approved the substitution and how it affected the result

Source: Compiled by the author.

For post-project analysis, it is important not merely to record that “there were problems with the technical specification” or that “materials were delayed.” It is necessary to establish the cause-and-effect relationship: what specific deviation occurred, when it was identified, how it affected timelines, quality, and cost, and which rule should be changed in subsequent projects [4].

2.2. Deviations at the Stages of Fabrication, Logistics, and Installation

The second group of deviations appears at the stages of direct fabrication, logistics, and installation. Some of them arise directly in the workshop or on site, but a significant share results from shortcomings in earlier preparation: an incomplete technical specification, errors in drawings, untimely material preparation, or weak coordination between departments [13].

At the fabrication stage, the most common deviations are related to cutting, welding, assembly, surface treatment, painting, and intermediate control [5]. An error in the dimensions of parts may lead to problems during assembly; deformation after welding may disrupt the geometry of the structure [6]; and insufficient surface preparation may result in painting defects or the need for repeated finishing.

Special attention should be paid to the moment when a defect is detected. If an error occurred at the cutting stage but was noticed only before installation, this indicates not only an execution error, but also weakness in the system of intermediate control [8]. The later a deviation is detected, the more expensive it becomes to correct.

At the logistics stage, problems may be related to packaging, transportation, loading, unloading, damage to the coating, or unaccounted dimensions of the structure. For large advertising, façade, or architectural metal structures, logistics must be taken into account as early as the design and kitting stages [15].

During installation, the most common issues are incomplete kitting, missing fasteners, mismatch between the installation scheme and actual site conditions, difficult access to the installation location, an unprepared fastening base, or the need for on-site modifications [16].

Stage	Typical Deviation	Possible Consequences	What Post-Project Analysis Records
Cutting	Error in the dimensions, quantity, or marking of parts	Rework of blanks, delay in assembly	Cause of the error: design documentation, performer, or lack of verification
Welding	Weld defects, deformations, non-compliance of joints	Repeated welding, disruption of geometry	At which stage the defect was identified
Assembly	Incompatibility of elements, inaccuracy of joints	Modifications, change in the work sequence	Whether the problem was embedded in the drawing or arose in the workshop
Finishing / painting	Surface defects, coating damage, repeated finishing	Longer timeline, additional costs	Whether control was carried out before painting
Kitting	Absence of fasteners, parts, or installation scheme	Downtime of the installation team, additional site visit	Which element was missing and who was responsible for checking it
Logistics	Damage, improper packaging, delivery problems	Modifications, installation delay	Whether dimensions, packaging, and delivery method were taken into account
Installation	Fastener mismatch, difficult access, site not ready	On-site modifications, postponed handover	Whether the risk could have been identified before the team's departure
Handover of completed work	Customer comments or mismatch with expectations	Additional work, reputational risks	Whether acceptance criteria were defined in the technical specification

Source: Compiled by the author.

In post-project analysis, it is important to distinguish among three points: where the deviation arose, where it was detected, and what consequence it had [11]. For example, if missing fasteners are discovered during installation, the deviation becomes apparent on site, but it most likely originated at the kitting stage or during the transfer of information to the installation team.

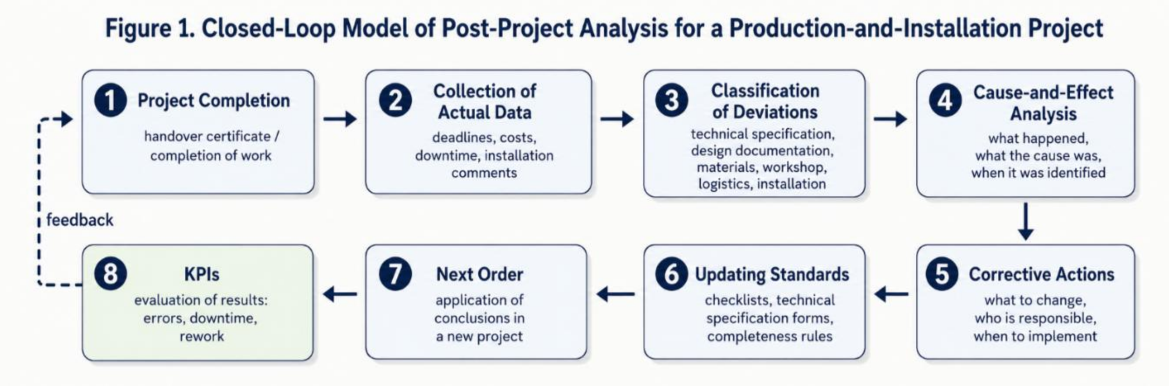
Thus, typical deviations in the production-and-installation cycle should not be viewed in isolation. They form an interconnected chain: incomplete initial data may lead to errors in drawings; errors in drawings may cause rework in the workshop; untimely material preparation may cause downtime; incomplete kitting may delay installation; and unaccounted site conditions may lead to additional site visits and on-site modifications.

3. Author's Methodology for Conducting Post-Project Analysis

Post-project analysis should not be a formal final meeting, but a clear management procedure that transforms the experience of a completed order into specific changes in the future process [11]. For the production of non-standard metal structures, this is especially important because each project has individual drawings, its own material specification, and a separate logic of fabrication, transportation, and installation.

The analytical core of the proposed methodology is based on three consecutive stages: collecting factual data after the handover of completed work, classifying deviations by stages of the production-and-installation cycle, and identifying causes with the development of corrective actions for subsequent orders [10]. At the same time, in practical application, the methodology has a broader closed-loop logic: from project completion and collection of factual information to updating internal standards, applying the conclusions to the next order, and verifying the result through KPIs.

The main idea of the methodology is that a completed project should not simply be "closed" after handover. In project-oriented organizations, the absence of a formalized mechanism for preserving experience increases the risk of knowledge loss after project completion or changes in the team composition [19]. The project should be briefly but systematically analyzed: what was completed according to plan, where deviations occurred, which of them recur, how they affected timelines, quality, and cost, and what changes should be made to the enterprise's work procedures [11].



Source: Compiled by the author.

3.1. Collection of Factual Data After Handover of Completed Work

The first stage is the collection of factual data [11]. It should be carried out immediately after the handover of completed work, while information about the project is still retained by the process participants: the designer, workshop supervisor, person responsible for materials, logistics specialist, installation team, and project manager [10].

At this stage, it is necessary to record not general impressions, but specific facts: whether there were delays, what changes were made, whether rework occurred, whether materials were sufficient, whether there were comments during installation, and whether the actual cost differed from the planned cost [11].

Source of Information	What Is Analyzed
Technical specification	Completeness of initial data, dimensions, installation conditions, requirements for materials and coating
Design documentation	Relevance of drawings, number of changes, detailing of joints, compliance with production and installation requirements
Material specification	Availability of metal, fasteners, components, paint, and consumables
Production schedule	Planned and actual timelines for cutting, welding, finishing, painting, and kitting
Change log	What was changed, when, by whom it was approved, and how it affected the process
Control points	Which defects or deviations were identified during fabrication
Installation team data	Problems with completeness, access to the site, fasteners, and the installation scheme
Final customer comments	Mismatches with expectations, additional work, claims, or clarifications
Actual costs	Material overruns, additional purchases, repeat site visits, and modifications

Source: Compiled by the author.

It is important that post-project analysis does not turn into a search for someone to blame. Its purpose is not to evaluate individual employees, but to identify weak points in the process. If a deviation recurs across different projects, this almost always indicates a problem not with an individual performer, but with the system: an incomplete technical specification form, unclear drawing approval procedure, weak completeness control, or the absence of a unified procedure for recording changes [12].

3.2. Classification of Deviations by Stages of the Production-and-Installation Cycle and Initial Identification of Causes

After factual data have been collected, deviations should be classified by stages of the production-and-installation cycle [10]. This makes it possible to understand where exactly the problem arose and where it was detected. In non-standard production, these two points often do not coincide: an error may arise at the technical specification stage, become apparent during design, and ultimately stop the work only at the installation stage [4].

For analysis, the following classification logic should be used:

technical specification → design → approval → material preparation → fabrication → quality control → kitting → logistics → installation → handover of completed work.

Each deviation should be linked to a specific stage [11]. This helps avoid general formulations such as “there was a delay,” “rework occurred,” or “installation was difficult.” For management purposes, it is important to know exactly why the delay occurred, what caused the rework, and at which stage the problem could have been prevented.

Cycle Stage	Typical Deviation	Primary Cause
Technical specification	Incomplete dimensions, absence of site data, unclear requirements for the final result	Insufficient preliminary review of initial data
Design	Insufficient detailing of joints, installation logic not taken into account	Incomplete review of design documentation before approval
Approval	Changes after drawings have been transferred to the workshop	Insufficiently formalized approval procedure
Material preparation	Absence of metal, fasteners, paint, or components	Late or inaccurate preparation of the specification
Fabrication	Cutting errors, deformations after welding, finishing defects	Insufficient intermediate control or inaccurate design documentation
Kitting	Missing fasteners, parts, or installation scheme	Absence of a completeness checklist
Logistics	Product damage, transportation difficulties	Unaccounted dimensions, insufficient packaging
Installation	On-site modifications, unprepared base, fastener mismatch	Unaccounted site conditions or incomplete transfer of information
Handover of completed work	Customer comments, additional work	Unclear acceptance criteria or changed expectations

Source: Compiled by the author.

Special attention should be paid to recurring deviations. If the same deviation appears in several projects, it should move from the category of a “one-time error” to the category of a “systemic problem” [12]. For example, if the installation team repeatedly encounters missing fasteners, the issue should be reviewed not as an isolated case, but as a problem in the kitting procedure before shipment.

Deviation Level	Characteristics	Example
One-time deviation	Occurred once and shows no signs of recurrence	Product damage during a specific transportation event
Recurring deviation	Occurs in different projects under similar conditions	Regular shortage of fasteners before installation
Systemic deviation	Related to the absence of a rule, procedure, or responsible person	Absence of mandatory verification of installation conditions at the technical specification stage

Source: Compiled by the author.

A one-time deviation may require a local solution, whereas a systemic deviation requires a change to an internal standard, document form, approval procedure, or responsibility matrix [1].

3.3. Identifying the Causes of Deviations and Developing Corrective Actions

After deviations have been classified, it is necessary to proceed to identifying their causes [4]. This is the most important stage of post-project analysis, because it is precisely this stage that transforms a description of a problem into a managerial decision [11]. If the enterprise limits itself to merely recording the fact, for example, “there was rework” or “installation was delayed,” it will not gain practical benefit.

To identify causes, it is advisable to use cause-and-effect logic [4]. Each deviation is analyzed through four questions:

1. What happened?
2. Where did the cause arise?
3. When was the deviation identified?
4. What needs to be changed in the process?

In practice, the causes of deviations should be grouped into informational, design-related, material, technological, organizational, installation-related, logistics-related, and communication-related categories [10].

Cause Group	Description	Example of Corrective Action
Information-related	Incomplete initial data, loss of information between departments	Update the technical specification form and add a mandatory section on installation conditions
Design-related	Errors or insufficient detailing of design documentation	Introduce a drawing review before transfer to the workshop
Material-related	Absence of materials or errors in the specification	Introduce a material readiness check before launch
Technological	Fabrication complexity, welding or finishing defects	Add an intermediate control point after a critical operation
Organizational	Unclear responsibility, weak planning	Assign a responsible person for each stage and readiness status
Installation-related	Missing fasteners, site not ready, difficult access	Introduce an installation checklist before shipment
Logistics-related	Damage, improper packaging, unaccounted dimensions	Update packaging and transportation rules
Communication-related	Oral changes, different drawing versions, uncommunicated comments	Use a change log and the current version of the design documentation

Source: Compiled by the author.

Oral changes, different versions of drawings, and uncommunicated comments should be controlled through a change log and the current version of the design documentation [9]. Review of complex joints by the workshop supervisor before launch should be considered an element of responsibility allocation for the quality of welding and assembly work [7].

A corrective action must be specific. It is not enough to write: “improve control” or “check drawings more carefully.” Combining cause-and-effect analysis with the logic of continuous improvement makes it possible to transform identified deviations into concrete actions for process improvement [23]. The action should answer the following questions: what exactly is being changed, who is responsible, when it must be implemented, and how the result will be verified [1].

Deviation	**Cause**	**Corrective Action**
The workshop was idle due to missing drawings	The project was transferred without confirmed design documentation status	Introduce the status “design documentation approved” as a mandatory condition for launch
Rework of a joint after welding	The drawing did not include detailed information on the fastening joint	Add a review of complex joints by the workshop supervisor before launch
The installation team did not have the required fasteners	There was no completeness checklist	Introduce a kitting sheet before shipment
Repeat site visit	Access conditions at the installation site were not taken into account	Add an “installation restrictions” section to the technical specification
Material overuse	The specification was prepared inaccurately	Introduce specification review by the person responsible for materials
Painting delay	Surface preparation and drying time were not taken into account	Update the calendar plan with dedicated time for coating

Source: Compiled by the author.

After corrective actions have been developed, it is important to ensure their implementation. For this purpose, each action must be assigned a responsible person, a deadline, and a status. Otherwise, the analysis will remain merely a description of problems rather than a tool for improvement.

Thus, post-project analysis in the production of non-standard metal structures should perform a feedback function. In make-to-order production, the regular use of factual data is important for updating planning decisions, since short-term deviations directly affect timelines, resource loading, and order fulfillment [21]. It connects the completed project with subsequent orders, helps reduce recurring errors, refine the enterprise’s internal rules, and gradually improve the manageability of the entire production-and-installation cycle.

4. Tools and Indicators of Post-Project Analysis

Post-project analysis should rely on specific tools for recording data [11]. If the results of a completed project remain only in the form of oral comments, the enterprise quickly loses valuable information: why a delay occurred, at which stage an error was formed, who should have prevented it, and how it affected timelines, quality, and cost [9].

In the production of non-standard metal structures, it is advisable to use three groups of tools: a post-project order card, a register of typical errors and recurring deviations, and a system of indicators for evaluating results [10].

4.1. Post-Project Order Card

The post-project order card is the main document in which the results of a completed production-and-installation project are summarized [8]. Its purpose is to record not only the fact that the work has been completed, but also the difference between the planned and actual progress of the order.

Unlike a standard production card, which accompanies the order during execution, the post-project card is completed after the handover of the work. It shows what was planned, what actually happened, which deviations occurred, why they happened, and which corrective actions need to be implemented [11].

Card Section	Information Content	Managerial Significance
Order data	Order number, project site name, type of structure, customer, project manager	Makes it possible to identify the completed project
Planned indicators	Planned launch date, completion date, shipment date, installation date, planned cost	Creates a basis for comparison
Actual indicators	Actual completion timelines, actual installation date, actual cost	Shows the real progress of the work
Deviations	Delays, rework, downtime, additional site visits, cost overruns, installation comments	Makes it possible to see where the project deviated from the plan
Causes	Incomplete technical specification, design documentation errors, lack of materials, weak kitting, installation restrictions	Helps move from problem description to root cause
Responsible stages	Technical specification, design, approval, material preparation, production, kitting, logistics, installation	Identifies the stage where control should be strengthened
Corrective actions	Changes to the technical specification form, drawing review, specification review, kitting procedure, installation preparation	Turns analysis into practical improvement

Source: Compiled by the author.

The post-project card should not be overly complex. Its value lies in the regularity of its use. If such a form is completed after every complex or problematic project, the enterprise gradually accumulates a real database of the causes of delays, rework, and cost overruns [1].

4.2. Register of Typical Errors, Changes, and Recurring Deviations

The post-project card provides information about a specific order, but this is not sufficient for systematic improvement. A tool is needed that makes it possible to identify recurring problems across different projects [11]. Such a tool is the register of typical errors, changes, and recurring deviations.

The register is formed on the basis of post-project cards, change logs, comments from the installation team, production modifications, and downtime data [9]. Its purpose is to show which problems occur not by chance, but systematically.

No.	Type of Deviation	Stage of Occurrence	Recurrence	Possible Cause	Corrective Action
1	Incomplete initial data	Technical specification	Recurring	Absence of a mandatory technical specification checklist	Add sections on installation conditions and measurements to the technical specification form
2	Drawing changes after launch into the workshop	Design / approval	Recurring	Insufficient review of design documentation before transfer to production	Introduce the status “design documentation approved for launch”
3	Downtime due to lack of material	Material preparation	Recurring	Specification prepared too late	Verify material readiness before launch
4	Rework of joints after welding	Fabrication	Periodic	Insufficient detailing of joints in the drawing	Submit complex joints for preliminary review by the workshop supervisor
5	Shortage of fasteners before installation	Kitting	Recurring	No kitting sheet	Introduce a completeness checklist
6	Coating damage during delivery	Logistics	Periodic	Insufficient packaging	Update packaging and marking rules
7	On-site modifications	Installation	Recurring	Access conditions or fastening base not taken into account	Add a preliminary site inspection before installation

Source: Compiled by the author.

The register should perform not an archival, but a managerial function. It should be reviewed periodically: for example, once a month or after the completion of several complex projects. If a particular deviation recurs, it should be moved into the category of a systemic problem [12]. After that, the enterprise should not merely “take the experience into account,” but change a specific rule: the technical specification form, the procedure for approving design documentation, specification review, completeness control, or the transfer of information to the installation team [1].

4.3. System of Indicators for Evaluating Order Results

Post-project analysis should have a measurable basis [10]. If the enterprise limits itself to general formulations — “the project was complex,” “installation was difficult,” “there were delays” — such conclusions are difficult to use for management. Therefore, it is necessary to record specific indicators that show how much the actual execution of the order differed from the planned one [1].

Indicator	What It Evaluates	Practical Significance
Completion timelines	Deviation of actual dates from planned dates: launch, readiness, shipment, installation, and handover of completed work	Shows at which stages delays occur

Number and duration of downtimes	How many times and for how long the process was stopped	Helps identify the causes of time losses
Scope of rework	Number of modifications, repeated operations, reworked parts or joints	Shows the quality of the technical specification, design documentation, production, and intermediate control
Material overuse	Difference between planned and actual consumption of metal, fasteners, paint, and components	Makes it possible to assess the accuracy of the specification and technological preparation
Number of installation comments	Comments from the installation team or customer during installation	Shows the quality of installation preparation, completeness, and information transfer
Deviation of actual cost from planned cost	Difference between planned and actual expenses	Makes it possible to assess the financial impact of deviations
Number of recurring errors	How many problems had already occurred in previous projects	Shows whether the system of learning from the enterprise's own experience is working

Source: Compiled by the author.

The number and duration of downtimes help identify the causes of time losses in the production process [13]. Material overuse makes it possible to assess the accuracy of the specification and technological preparation [15]. Each of these indicators must be linked to a specific managerial conclusion [10]. For example, if the duration of downtime due to lack of materials is constantly increasing, the procedure for preparing specifications and confirming material readiness should be reviewed. If the number of installation comments increases, the verification of completeness, the installation scheme, and site conditions should be strengthened.

Thus, the tools and indicators of post-project analysis form a single system. The post-project card records the actual progress of a specific order, the register of typical errors shows recurring deviations across projects, and the system of indicators makes it possible to assess their impact on timelines, quality, installation, and cost.

5. Practical Use of Post-Project Analysis Results

Post-project analysis has value only when its results are translated into specific changes in the enterprise's operations [11]. If, after project completion, a delay, rework, material overuse, or installation comment is recorded, but the work procedure does not change, such information does not affect the efficiency of subsequent orders.

The practical use of analysis results consists in transforming the experience of a completed project into internal production rules, updated checklists, refined technical specification forms, drawing requirements, procedures for checking material readiness, kitting rules, and procedures for transferring information to the installation team [1].

5.1. Transforming Analysis Results into Internal Production Rules

The results of post-project analysis should be formalized as simple and clear rules that can be applied to subsequent orders [1]. For the production of non-standard metal structures, it is especially important that these rules not be overly general. Formulations such as "better control the drawings" or "check completeness more carefully" do not create real change. An effective rule must clearly define what exactly needs to be checked, at which stage, who is responsible, and under what conditions the project may proceed to the next stage [8].

Identified Problem	Post-Project Analysis Conclusion	Internal Production Rule
Design delay due to an incomplete technical specification	Not all initial data were collected at the start	The order is not transferred to the designer without a complete technical specification section
Rework of a joint after welding	The drawing did not contain sufficient detailing	Complex joints must be approved with the workshop supervisor before launch
Downtime due to lack of material	The specification was prepared late	Material readiness is checked before the order is transferred to the workshop
Shortage of fasteners during installation	There was no completeness checklist	A kitting sheet must be completed before shipment
Coating damage during delivery	Packaging did not correspond to the dimensions and type of surface	A separate packaging procedure is used for products with decorative coating
Additional installation visit	Site access conditions were not taken into account	Before installation, access, fastening base, equipment, and permit conditions must be checked

Source: Compiled by the author.

Such rules should be incorporated into the enterprise's internal documents: the technical specification form, drawing review checklist, material readiness card, kitting sheet, installation card, or change log [9]. This makes it possible to turn post-project analysis from a one-time action into part of the management system.

5.2. Using Conclusions in Subsequent Orders

The main purpose of post-project analysis is to improve the execution of subsequent orders [11]. A completed project should become a source of information for a new one, especially if the product is similar in type, materials, installation conditions, or technological complexity.

In the production of non-standard metal structures, there may be no exact repetition of products, but typical situations often recur: façade installation, large advertising structures, stainless-steel products, complex fastening joints, decorative coatings, limited access to the site, the need for non-standard fasteners, or complex logistics. If the enterprise has already encountered such conditions, the conclusions from previous projects should be used at the preparation stage of a new order [11].

Stage of the New Order	How Post-Project Analysis Conclusions Are Used
Formulation of the technical specification	Questions that previously caused clarifications or delays are added to the technical specification form
Design	The designer checks typical joints that previously led to rework
Approval of design documentation	Complex solutions are additionally coordinated with the workshop and installation team
Material preparation	Critical materials are checked earlier, before launch into the workshop
Fabrication	Intermediate control points are introduced for operations where defects previously occurred
Kitting	A completeness checklist is used before shipment

Logistics	Updated packaging rules are applied for oversized or delicate products
Installation	The installation team receives the current scheme, list of fasteners, and site information
Handover of completed work	Acceptance criteria are clarified at the beginning of the order

Source: Compiled by the author.

The results of post-project analysis can also be used for employee training [1]. This does not refer to formal instruction sessions, but to a brief review of typical situations: why a delay occurred, what caused rework, why the installation team did not have complete information, and which data should have been collected earlier.

5.3. Conditions for Effectiveness and Limitations of the Approach

The effectiveness of post-project analysis depends on how systematically the enterprise records data during project execution [1]. If information about changes, downtime, rework, material shortages, or installation comments is not preserved, it will be difficult to determine the real causes of deviations after the work has been completed.

The first condition for effectiveness is regularity [11]. Post-project analysis should be conducted after every complex, problematic, or representative order. For small typical jobs, a brief record of the main deviations is sufficient, but for non-standard structures involving installation, changes, or cost overruns, a more detailed review is required.

The second condition is the participation of key performers: the designer, workshop supervisor, person responsible for materials, logistics specialist, installation team, and project manager [10]. This makes it possible to view the problem from different perspectives and avoid superficial conclusions.

The third condition is the recording of corrective actions [1]. If the analysis does not define what exactly needs to be changed, who is responsible, and when the action must be implemented, the practical value of such analysis decreases.

Condition for Effectiveness	**Practical Significance**
Regular conduct of analysis	The experience of completed projects is not lost
Complete recording of factual data	The causes of deviations can be established on a substantiated basis
Participation of key performers	The problem is analyzed from the perspective of the technical specification, design documentation, workshop, materials, and installation
Specific corrective actions	The analysis results in changes to rules or procedures
Assignment of responsible persons	Conclusions are translated into practical implementation
Updating internal documents	New experience is embedded in forms, checklists, and cards
Monitoring the recurrence of errors	The enterprise can see whether the problem is actually decreasing

Source: Compiled by the author.

At the same time, the proposed approach has limitations. It does not replace professional design, technological competence, or high-quality execution of welding, assembly, or installation work [6]. Post-project analysis cannot correct the errors of an already completed project, but it can reduce the likelihood of their recurrence in the future.

Thus, the practical use of post-project analysis results depends not on the complexity of the form, but on the discipline of its application. If an enterprise regularly records deviations, identifies their causes, develops corrective actions, and applies them in subsequent orders, post-project analysis becomes a real tool for improving the production of non-standard metal structures.

6. Testing the Post-Project Analysis Methodology Based on a Generalized Practical Example

To demonstrate the practical significance of the proposed methodology, a conditional example of a production-and-installation project involving the fabrication and installation of a non-standard façade metal structure for a commercial facility may be considered. Such a project involves the development of individual drawings, selection of materials and fasteners, workshop fabrication, painting or other finishing, transportation, and on-site installation.

Within the conditional example, the following deviations were recorded during the execution of the first project: incomplete data regarding the fastening base, changes in drawings after launch into the workshop, delayed delivery of certain materials, rework of some joints, shortage of fasteners before installation, and an additional site visit by the installation team. After the handover of the completed work, post-project analysis was conducted, and corrective actions for the next similar order were developed based on its results.

The proposed methodology shows that the effect of post-project analysis is achieved not through one isolated decision, but through the consistent elimination of the causes of recurring errors [12].

6.1. Reducing Recurring Errors in the Technical Specification, Drawings, and Material Preparation

The first result of applying post-project analysis is a reduction in the number of errors at the preparatory stages. The technical specification, design documentation, and material preparation largely determine the stability of the entire subsequent production-and-installation cycle [14].

In the example considered, after completion of the first project, it was established that some of the problems had arisen even before the order was launched into the workshop. In particular, the type of façade base, access conditions to the installation site, list of fasteners, and requirements for certain joints had not been fully clarified. As a result, the drawings had to be clarified during fabrication, and the workshop received changes after work had already begun.

Post-project analysis made it possible to transform these comments into specific rules for the next order: expand the technical specification form, strengthen approval of complex joints, and verify the material specification before launch into production [11].

Identified Problem	Corrective Action	Expected Result
Incomplete data regarding the fastening base	Added an “installation conditions” section to the technical specification	Fewer clarifications during design and installation
Drawing changes after launch into the workshop	Introduced the status “design documentation approved for launch”	Fewer changes after fabrication begins
Insufficient detailing of the joint	Introduced preliminary review of complex joints by the workshop supervisor	Less rework during welding and assembly
Incomplete specification	Introduced material verification before launch	Lower risk of material shortages
Unaccounted installation elements	Added the installation kit to the specification	More complete kitting before shipment

Source: Compiled by the author.

Thus, post-project analysis makes it possible not merely to record problems with the technical specification or drawings, but to change the very procedure for preparing subsequent orders.

6.2. Reducing Downtime, Rework, and Installation Comments

The second result is reflected in the reduction of downtime, rework, and installation comments. The conditional example shows that most such losses arise because of insufficient preparation at previous stages or weak transfer of information among process participants [13].

In the first project, workshop downtime was associated with waiting for an updated drawing and the absence of some materials. Rework of joints occurred because of insufficient detailing of the design documentation, while the additional installation visit resulted from missing fasteners and incomplete transfer of information to the installation team.

After the analysis, three key changes were implemented: verification of design documentation readiness before launch, confirmation of material readiness before transfer to the workshop, and use of a kitting sheet before shipment [8].

The indicators below are conditional and are used to demonstrate the logic of result evaluation.

Indicator	Problem Project / Before Post-Project Analysis	Next Project / After Corrective Actions	Managerial Conclusion
Number of technical specification clarifications after the start of design	7	2	The expanded technical specification form reduces the number of late clarifications
Number of design documentation changes after launch into the workshop	4	1	Preliminary approval of design documentation stabilizes the production process
Workshop downtime due to waiting for drawings or materials	12 hours	3 hours	Readiness verification before launch reduces time losses
Number of joint reworks	3	1	Preliminary review of complex joints reduces the risk of modifications
Additional installation visits	2	0	A complete installation package reduces repeat site visits
Deviation of actual cost from planned cost	+11%	+3%	Reduction of downtime and rework improves financial manageability

Source: Compiled by the author.

The comparison presented demonstrates that the effectiveness of post-project analysis should be evaluated not by the mere fact that the analysis was conducted, but by changes in measurable indicators in subsequent orders. A reduction in the number of technical specification clarifications, design documentation changes after launch into the workshop, downtimes, reworks, and additional installation visits indicates that corrective actions were transferred from the level of conclusions into practical production rules.

This comparison shows that the effectiveness of post-project analysis should be assessed not only by the fact that it was carried out, but by whether the recurrence of specific problems decreases in subsequent orders. For enterprises in the metalworking sector, loss management based on Lean principles is directly connected with reducing production costs and improving process efficiency [24].

6.3. Formation of the Enterprise’s Internal Standards Based on Practical Experience

The third result of applying the methodology lies in the formation of the enterprise’s internal standards. For the production of non-standard metal structures, this is especially important because the product itself cannot be fully standardized. Instead, the procedure for working with an order can be standardized: what data are collected, how drawings are approved, when materials are checked, who is responsible for completeness, and how information is transferred to the installation team [1].

Post-project analysis should end not with a general conclusion, but with the updating of specific internal rules. If a delay occurred because of an incomplete technical specification, the technical specification form is revised. If rework occurred because of insufficient joint detailing, the design documentation review is strengthened. If installation was delayed because of missing components, a kitting sheet is introduced [8].

Post-Project Analysis Conclusion	**Internal Standard Being Formed**	**Responsible Party**
The project cannot be launched without complete initial data	Technical specification checklist before design	Project manager
Complex joints require preliminary review	Approval of joints with the workshop supervisor	Designer, workshop supervisor
Materials must be confirmed before launch	Material readiness card	Person responsible for procurement
Completeness must be checked before shipment	Kitting sheet for the installation kit	Workshop supervisor
All changes must be recorded	Change log and control of the current version of design documentation	Project manager

Source: Compiled by the author.

The formation of such standards does not mean excessive bureaucratization of production. Their purpose is not to complicate work, but to reduce the number of situations in which decisions are made too late or communicated orally.

Thus, the results of applying the post-project analysis methodology are not limited to correcting individual shortcomings. The main value lies in the fact that a completed project becomes a source of specific changes in the process: document forms are refined, control points are strengthened, responsible persons are assigned, and rules for kitting and information transfer are updated. This is how accumulated experience is transformed into the enterprise’s internal standards, which reduce recurring errors and improve the manageability of non-standard metal structure production [11].

Conclusions

The article examined post-project analysis as a tool for improving the production of non-standard metal structures. It was established that, under conditions of custom and low-volume production, project completion should not be limited only to handover of the work to the customer or final quality control. A completed project should be viewed as a source of managerial information that makes it possible to identify the causes of deviations, recurring errors, and areas for improving future orders [11].

It was determined that the production of non-standard metal structures has a project-oriented character. Each order differs in its individual technical specification, drawings, structural joints, material specification, production route, transportation logic, and installation conditions. For this reason, it is impossible to fully standardize the final product; however, the procedure for working with the order can and should be standardized [1].

In the course of the study, the distinction between post-project analysis and final quality control was substantiated. Final quality control answers the question of whether the finished product complies with the technical specification, drawings, and acceptance criteria. Post-project analysis has a broader managerial meaning: it determines what exactly needs to be changed in the process so that the next order can be completed faster, at lower cost, with higher quality, and with fewer recurring errors [11].

Typical deviations in the production-and-installation cycle were systematized. These include incomplete initial data, inaccuracies in the technical specification, insufficient detailing of design documentation, changes after launch into the workshop, errors in material specifications, downtime caused by lack of resources, fabrication defects, damage during logistics, incomplete kitting, and installation comments. It was shown that such deviations should not be considered in isolation, since they often form a cause-and-effect chain: an error at the technical specification stage may appear later in drawings, production, kitting, or already during installation.

The proposed post-project analysis methodology involves three consecutive stages: collecting factual data after handover of completed work, classifying deviations by stages of the production-and-installation cycle, and identifying causes with the development of corrective actions. This approach makes it possible to move from general formulations such as “there were delays” or “rework occurred” to a specific managerial conclusion [10].

The tools of post-project analysis are of particular importance. The post-project order card makes it possible to record planned and actual indicators, main deviations, causes, responsible stages, and corrective actions. The register of typical errors, changes, and recurring deviations allows information to be accumulated across different projects and systemic problems to be identified [9]. The system of evaluation indicators — completion timelines, downtime, scope of rework, material overuse, installation comments, deviation of actual cost from planned cost, and number of recurring errors — creates a measurable basis for managerial decisions [10].

The practical use of post-project analysis results consists in transforming conclusions into internal production rules. If a delay occurred because of incomplete initial data, the technical specification form should be updated. If rework was related to insufficient detailing of joints, the review of design documentation before launch into production should be strengthened. If the installation team encounters a shortage of fasteners, it is advisable to introduce a kitting sheet before shipment. It is precisely this approach that transforms post-project analysis from a formal summary into a tool for real improvement.

Based on a hypothetical example, it was shown that the application of the methodology can help reduce recurring errors in the technical specification, drawings, and material preparation; decrease downtime, rework, and installation comments; and improve control over actual cost. The greatest effect is achieved when the results of the analysis are used not once, but systematically — in subsequent orders, checklists, cards, registers, and the enterprise’s internal standards.

At the same time, the effectiveness of the proposed approach depends on the discipline of recording data during project execution. If changes are communicated orally, the causes of downtime are not recorded, material substitutions are not approved, and installation comments are not entered into the order card, post-project analysis will be incomplete. Therefore, it is advisable to combine it with an order card, change log, control points, kitting sheets, and responsibility for implementing corrective actions [1].

Thus, post-project analysis is an important tool for the continuous improvement of non-standard metal structure production. Its main value lies not only in recording the shortcomings of a completed project, but in creating a system through which the enterprise learns from its own production experience. As a result, individual errors are transformed into internal rules, recurring deviations into corrective actions, and completed projects into a basis for higher-quality, more predictable, and economically manageable execution of subsequent orders.

References

[1] ISO 9001:2015. Quality management systems — Requirements. International Organization for Standardization, 2015.
[2] ISO 21502:2020. Project, programme and portfolio management — Guidance on project management. International Organization for Standardization, 2020.

[3] ISO 10006:2017. Quality management — Guidelines for quality management in projects. International Organization for Standardization, 2017.
[4] ISO 31000:2018. Risk management — Guidelines. International Organization for Standardization, 2018.
[5] BS EN 1090-2:2018+A1:2024. Execution of steel structures and aluminium structures — Technical requirements for steel structures. British Standards Institution, 2024.
[6] ISO 3834-2:2021. Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements. International Organization for Standardization, 2021.
[7] ISO 14731:2019. Welding coordination — Tasks and responsibilities. International Organization for Standardization, 2019.
[8] ISO 10005:2018. Quality management — Guidelines for quality plans. International Organization for Standardization, 2018.
[9] ISO 10007:2017. Quality management — Guidelines for configuration management. International Organization for Standardization, 2017.
[10] Project Management Institute. A Guide to the Project Management Body of Knowledge (PMBOK® Guide). 7th ed. Project Management Institute, 2021.
[11] Schindler, M., Eppler, M. J. Harvesting project knowledge: a review of project learning methods and success factors. *International Journal of Project Management*, 21(3), 2003. P. 219–228.
[12] Womack, J. P., Jones, D. T. Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Free Press, 2003.
[13] Goldratt, E. M., Cox, J. The Goal: A Process of Ongoing Improvement. North River Press, 2012.
[14] Slack, N., Brandon-Jones, A. Operations Management. 9th ed. Pearson, 2019.
[15] Chopra, S., Meindl, P. Supply Chain Management: Strategy, Planning, and Operation. 7th ed. Pearson, 2019.
[16] ISO 45001:2018. Occupational health and safety management systems — Requirements with guidance for use. International Organization for Standardization, 2018.
[17] Hou, B. X., El-Gayar, O. F. Two decades of design research on lessons-learned systems: a systematic review and future research agenda. *Issues in Information Systems*, 25(4), 2024. P. 373–391. DOI: 10.48009/4_iis_2024_130.
[18] Kamudyariwa, X. B., Osobajo, O. A., Oke, A., Adebayo, Y. Application of the systemic lessons learned knowledge model to learning in complex projects: How project practitioners are shaping their learning. *Management Learning*, 57(1), 2026. P. 120–144. DOI: 10.1177/13505076251339433.
[19] Nyallu, B. A., Deng, X., Ibrahim, A. S. Knowledge Loss in Construction Project-Based Organizations: The Role of Project Features, Knowledge Withholding, Fear, and Teams Interaction. *Sustainability*, 17(21), 2025. Article 9880. DOI: 10.3390/su17219880.
[20] Schulze, F., Dallasega, P. Lean and Industry 4.0 mitigating common losses in Engineer-to-Order theory and practice: an exploratory study. *Flexible Services and Manufacturing Journal*, 36, 2024. P. 780–820. DOI: 10.1007/s10696-023-09503-z.
[21] Woschank, M., Dallasega, P., König, A., et al. Potentials of using real-time data to increase the update frequency of production planning and control strategies in MTO: a discrete event simulation study. *Flexible Services and Manufacturing Journal*, 36, 2024. P. 760–779. DOI: 10.1007/s10696-024-09550-0.
[22] Pietsch, D., Matthes, M., Wieland, U., Ihlenfeldt, S., Munkelt, T. Root Cause Analysis in Industrial Manufacturing: A Scoping Review of Current Research, Challenges and the Promises of AI-Driven Approaches. *Journal of Manufacturing and Materials Processing*, 8(6), 2024. Article 277. DOI: 10.3390/jmmp8060277.
[23] Botelho, H., Peças, P., Jorge, D., Mcleod, J., Albertoni, L., de Oliveira, L. C., Leite, M. Data-Driven Root-Cause Analysis in the Scope of Continuous Improvement Projects. In: *Advances in Production Management Systems. Production Management Systems for Volatile, Uncertain, Complex, and Ambiguous Environments*. IFIP Advances in Information and Communication Technology, Vol. 730. Springer, 2024. P. 31–45. DOI: 10.1007/978-3-031-71629-4_3.
[24] Zaky, N., Ahmed, M. Z., Alarjani, A., Attia, E. A. Lean manufacturing implementation in iron and steel industries: effect of wastes management on the production costs. *Journal of Engineering, Design and Technology*, 23(2), 2025. P. 525–545. DOI: 10.1108/JEDT-01-2023-0012.