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Optimization of the Production-and-Installation Cycle for Custom Metal Structures in Low- and Medium-Volume Manufacturing

Yuriy Kanalin

Abstract

The article examines the optimization of the production-and-installation cycle for custom metal structures in low- and medium-volume manufacturing. It substantiates that the main losses in this field arise not only during individual technological operations, but primarily at the interfaces between stages: formulation of the technical specification, design, material preparation, workshop fabrication, quality control, logistics, and installation.

Based on the author's practical experience, the article proposes a model for optimizing the production-and-installation process. The model includes preliminary verification of the technical specification, assessment of the project's design, technological, and material readiness, coordination between the designer, workshop, and installation team, use of a unified order card, calendar-and-resource planning, change management, and a system of control points.

The practical value of the model 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, and industrial facilities. The proposed approach helps reduce downtime, decrease the number of reworks, improve the quality of interaction between departments, and ensure more predictable project execution.

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Keywords:

custom metal structures;
production-and-installation cycle;
low-volume manufacturing;
quality control;
material preparation;
design documentation;
order card;
KPI;
installation of metal structures.

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Introduction

The modern development of the construction, advertising-production, and industrial sectors has led to growing demand for custom metal structures in low- and medium-volume manufacturing. These products include non-standard advertising structures, façade and architectural metal elements, frames, stainless-steel products, and structures for commercial, warehouse, and industrial facilities. Their creation requires not only the high-quality execution of individual technological operations, but also the clear organization of the full work cycle [1]. This cycle includes receiving the technical specification, developing design documentation, fabrication, quality inspection, logistics, and on-site installation.

The relevance of this topic is connected with the high variability of custom metal structures. Each project may differ in dimensions, materials, structural joints, fastening methods, appearance requirements, operating conditions, and installation specifics. Such variability is characteristic of multi-product low-volume manufacturing, where efficiency depends not only on the productivity of individual operations, but also on the enterprise's ability to manage different types of orders within a single production flow [19]. Under these conditions, an enterprise cannot always apply approaches typical of mass production [16]. Each structure requires separate technical analysis, adaptation of drawings, selection of materials, and coordination of actions among several departments. These conditions correspond to engineer-to-order production, which is characterized by planning complexity, frequent changes in requirements, and the need for close interaction among design, procurement, and production [21].

The practice of fabricating and installing non-standard metal structures shows that a significant share of losses arises not directly in the workshop, but at the transitions between stages. An incomplete technical specification, inaccurate measurements, delayed approval of drawings, delays in material supply, or insufficient preparation for installation may cause downtime, rework, cost overruns, and missed deadlines [4]. Therefore, efficiency in this field is determined not only by the technical capabilities of equipment or the qualifications of workers, but also by the level of organization of the entire process — from the first contact with the customer to the handover of the completed project.

The research problem lies in the fact that, under conditions of low- and medium-volume manufacturing, it is impossible to fully standardize the product itself: each structure has its own technical, operational, and installation-specific features. At the same time, the project workflow can be standardized: collection of initial data, design, resource provision, planning of workshop operations, quality inspection, logistics, and installation. It is process standardization, rather than unification of the final product, that forms the basis for reducing downtime, decreasing the number of errors, and improving the predictability of the production-and-installation cycle [1]. For make-to-order production, it is important not only to plan individual operations, but also to select a workflow management system that takes into account the order release sequence and the actual loading of resources [18].

The purpose of this article is to develop and substantiate a practice-oriented model for optimizing the production-and-installation cycle for custom metal structures in low- and medium-volume manufacturing. The model is aimed at improving work planning, reducing downtime, decreasing rework, and enhancing the quality of coordination among the design, production, and installation departments.

To achieve this purpose, the following tasks have been defined:

1. Determine the specific features of manufacturing custom metal structures in low- and medium-volume production.
2. Analyze the main stages of the production-and-installation cycle.
3. Identify typical causes of downtime, delays, and rework.
4. Assess the role of design documentation, material preparation, and workshop planning in reducing production losses.
5. Propose a coordination model among the design, production, and installation departments.
6. Develop a system of control points for the key stages of the cycle.
7. Define performance indicators for the proposed model.

The object of the research is the production-and-installation cycle for custom metal structures in low- and medium-volume manufacturing.

The subject of the research is the organizational, technological, and managerial approaches to optimizing this cycle, in particular methods of work planning, coordination between departments, quality control, reduction of downtime, and improvement of project schedule predictability.

The methodological basis of the article consists of a process-based approach to analyzing the production-and-installation cycle, practical generalization of experience in implementing production and installation projects, analysis of typical causes of losses, and comparison of traditional and optimized approaches to organizing work [3]. To assess the effectiveness of the proposed model, performance indicators related to deadlines, downtime, rework, and installation risks are also used.

The scientific novelty of the article lies in the development of a process model for managing the production-and-installation cycle of custom metal structures in low- and medium-volume manufacturing. The proposed model combines control over the readiness of the technical specification, design documentation, material supply, product completeness, and installation logic into a single system for managerial decision-making. Unlike an approach in which individual stages are performed in isolation, the proposed model makes it possible to view the fabrication and installation of a custom metal structure as an integrated, manageable process.

The practical value of the proposed model lies in its applicability to enterprises that work with non-standard metal structures in low- and medium-volume manufacturing. This approach systematizes work with individual projects, reduces dependence on oral communication, improves the quality of technical preparation, decreases the number of errors at the fabrication and installation stages, and makes project completion timelines more predictable.

1. Specific Features of Manufacturing Custom Metal Structures in Low- and Medium-Volume Production

The manufacture of custom metal structures in low and medium production runs is a complex manufacturing and installation process that requires a combination of engineering precision, technological discipline, and flexible management [5]. Unlike mass production, where efficiency is based on product repeatability, in the field of custom metal structures, each project has its own technical, design, and installation characteristics.

Such products may vary in terms of dimensions, materials, fasteners, surface requirements, transportation methods, and operating conditions. Therefore, the result depends not only on the equipment or the qualifications of the workers, but also on the quality of project preparation, the accuracy of the drawings, the timely delivery of materials, and coordination between the design, manufacturing, and installation departments [16].

1.1. Technological and Organizational Features of Custom Metal Structures

The technological specificity of custom metal structures lies in the high variability of the products. Within a single production facility, projects of varying complexity can be carried out simultaneously: from small stainless steel products to large-scale advertising or facade structures [5]. Each of these requires a separate analysis of geometry, materials, joining methods, coatings, and installation.

The quality of the source data is of particular importance. For a custom-made product, a general sketch or a verbal description from the customer is not sufficient. Precise dimensions, photos of the object, information about the installation site, surface type, equipment availability, operating conditions, and possible installation constraints are required [2]. If this data is not collected at the initial stage, the risk of errors carries over to the workshop and the installation phase.

An important factor is the manufacturability of the design. The drawing must take into account not only the product's appearance and strength, but also the actual sequence of its manufacturing: cutting, welding, assembly, grinding, painting, packaging, and delivery [5]. Therefore, the design solution should also be evaluated in terms of labor intensity, material availability, and ease of assembly.

The organizational characteristic of this type of production is that the company cannot operate according to the logic of a fully standardized assembly line. A flexible management system is required, in which each project goes through distinct stages: verification of technical specifications, preparation of drawings, material procurement, workshop scheduling, interim quality control, preparation for installation, and post-completion analysis [2].

In the production of custom metal structures, it is the process of creation—not the product itself—that should be standardized. This reduces chaos, prevents information loss between departments, and makes the execution of non-standard projects more manageable [1].

1.2. Differences Between Low- and Medium-Volume Manufacturing and Mass Production

Low- and medium-volume manufacturing occupies an intermediate position between custom manufacturing and mass production. On the one hand, the company performs repetitive manufacturing operations: cutting, welding, assembly, surface treatment, painting, and installation [16]. On the other hand, the final products are often not entirely standard and require customization.

In mass production, efficiency is achieved through product repeatability, a stable production process, and a minimum number of changes after production begins [14]. Documentation is created once and reused multiple times. In low- and medium-volume production of steel structures, drawings, specifications, and assembly solutions are often developed or refined for a specific project [16].

Criterion	Mass Production	Low- and Medium-Volume Manufacturing of Custom Metal Structures
Product type	Standardized	Custom or partially typical
Documentation	Repetitive	Adapted to a specific project

Planning	Stable technological route	Flexible, depending on product complexity
Risk of changes	Low	Higher due to clarifications and installation conditions
Role of installation	Not always critical	Often a key final stage
Source of efficiency	Scale and repeatability	Coordination, verification, and high-quality preparation

Source: Compiled by the author.

The main management challenge lies in the need to combine technical flexibility with process discipline. If each project is organized differently, the risk of information loss, errors, and delays increases. If, on the other hand, the workflow is standardized, even a non-standard product can be manufactured in a more predictable manner [13].

1.3. Main Risks of Custom Orders: Timelines, Quality, and Cost

Custom orders are always associated with a higher level of uncertainty [4]. In production based on a custom engineering design, planning flexibility is one of the key factors in minimizing the impact of uncertainty on project timelines [20]. The main risks of such production can be grouped into three categories: project timelines, product quality, and production costs.

Delays usually arise not from a single cause, but from a chain of inconsistencies. An incomplete technical specification delays the development of drawings; late approval of design documentation delays the procurement of materials; and the lack of materials leads to workshop downtime or the postponement of installation [17].

The risk of reduced quality stems from the fact that a custom design must meet not only strength requirements but also requirements for geometry, welds, surface finish, coating, completeness, and ease of installation [6]. If inspection is carried out only at the very end, defects are discovered too late.

Rising production costs in custom manufacturing are often caused by rework, downtime, material overuse, urgent purchases, redeliveries, or additional on-site installation visits [13].

Risk Group	Causes	Consequences	Mitigation Method
Timelines	Incomplete technical specification, delayed drawings, shortage of materials	Schedule shifts, downtime, postponed installation	Preliminary verification, calendar planning
Quality	Errors in documentation, weak intermediate control	Defects, rework, non-compliance with requirements	Control points
Cost	Overuse of materials, modifications, additional site visits	Reduced project profitability	Accurate specification, change control
Installation	Unaccounted site conditions	On-site modifications, delayed handover	Preliminary site analysis
Communication	Loss of information between departments	Execution errors, duplication of work	Unified order card

Source: Compiled by the author.

Thus, the specific nature of manufacturing custom metal structures lies in the need to combine the technical uniqueness of each product with a well-organized process. The best results are achieved when, even before production begins, the technical parameters have been defined, the drawings have been approved, the materials have been verified, the assembly sequence is clear, and the responsible personnel have been assigned.

2. Analysis of the Production-and-Installation Cycle of an Order

It is advisable to view the production and assembly cycle for manufacturing a custom metal structure as a sequence of interrelated stages, each of which affects the completion time, the quality of the final product, and the actual cost of the project [2]. For custom engineering orders, it is advisable to integrate production planning with the project schedule, since a change in one stage directly affects subsequent operations and resource requirements [22]. In the field of custom metal structures, the greatest challenges arise not only during actual manufacturing in the workshop but also at the transitions between stages: from the technical specifications to design, from design to workshop execution, and from production to installation.

In generalized form, the production-and-installation cycle can be presented as follows:

Technical specification → design → approval → procurement of materials → preparation of design documentation → cutting → welding → quality control → painting/finishing → assembly and completion → logistics → installation → handover of completed work.

In practice, certain stages may be carried out in parallel [16]. For example, the preliminary procurement of standard materials may begin even before the design documentation is finalized, provided that the technical parameters have already been confirmed. At the same time, starting major workshop operations without a complete set of drawings, specifications, and approvals creates a high risk of rework.

2.1. Main Stages of Order Processing: From Technical Specification to Installation

The process of developing a custom project begins with the creation of technical specifications. At this stage, the basic parameters of the future design are defined: the product's intended use, dimensions, materials, operating conditions, aesthetic requirements, mounting method, completion deadlines, and the characteristics of the installation site.

Once the technical specifications are finalized, the design phase begins. Its objective is to transform the customer's needs into a technically feasible solution that takes into account geometry, strength, manufacturability, transportation, and installation safety [5].

Next, technical and design solutions are finalized. At this stage, it is necessary to agree on the product's appearance, materials, finishes, fasteners, completion deadlines, and installation conditions. Formal approval shifts the risks to the workshop, where correcting errors requires significantly more resources.

Once approval is gained, the material base is established: metal, fasteners, components, consumables, paint, or other coatings are purchased or reserved. For custom structures, it is important that procurement be based on precise specifications [17]. The preparation of design documentation ensures that the technical solution is transferred to production, and the workshop stage includes cutting, welding, assembly, surface treatment, and interim quality control [8].

The final stages include assembly, logistics, installation, and project handover. Before shipment, it is necessary to check not only the product itself but also that all fasteners, auxiliary parts, the installation diagram, and up-to-date information for the installation team are present [9].

Stage	**Key Result**	**Typical Risk**
Technical specification	Initial data are formed	Incomplete or inaccurate information
Design	Structural solution is developed	Failure to account for production or installation conditions

Approval	Solution is confirmed	Changes after the start of work
Procurement of materials	Material availability is ensured	Delivery delays or errors in the specification
Preparation of design documentation	Complete set of documentation	Insufficient detailing
Cutting	Set of blanks is prepared	Errors in dimensions or quantity
Welding	Structure is formed	Deformations, weld defects
Quality control	Deviations are identified before final finishing	Late detection of defects
Painting/finishing	Finished product with the required appearance	Damage or poor-quality surface preparation
Completion/kitting	Complete set ready for shipment	Missing individual elements
Logistics	Structure delivered to the site	Damage during transportation
Installation	Product installed	Unaccounted site conditions
Handover of completed work	Project completed	Comments due to mismatch with expectations

Source: Compiled by the author.

This diagram shows that the production and installation cycle is not merely a sequence of technical operations, but a project management system [2]. Each stage must have a clear outcome that provides a basis for moving on to the next stage without critical risks.

2.2. The Role of Design, Material Preparation, and Workshop Planning

In the production of custom metal structures, three interrelated components are of particular importance: design, material preparation, and workshop planning [16].

Design is the foundation of the entire process. A high-quality drawing should address not only how the structure should be designed, but also how it should be manufactured, transported, and assembled. Effective design must take into account the availability of materials, the sequence of manufacturing operations, the feasibility of high-quality welding and machining, transportation constraints, the method of installation, access to fastening points, and subsequent maintenance of the structure [5].

Material preparation is critical to stable operations. In a custom manufacturing environment, aligning the requirements of a specific order with the availability of materials and production resources is one of the key factors in the stable execution of a project [23]. Even with high-quality documentation, a workshop cannot operate without metal, fasteners, consumables, paint, or components [17]. Therefore, specifications should be finalized as early as possible, and critical materials should be checked for delivery dates.

Workshop planning ensures that work is actually completed within the established deadlines. For steel structure fabrication projects, optimizing the workflow and resource utilization directly affects the efficiency of production capacity utilization [24]. A practical approach is one that takes into account the project's actual readiness for launch: the availability of approved technical specifications, drawings, materials, responsible contractors, and an agreed-upon installation date [16].

In practical work, a project moves into production only after three conditions have been verified:

Documentation readiness — drawings, specifications, approved joints, and coating requirements are available.

Material availability — metal, fasteners, components, and consumables are available or have a confirmed delivery date.

Organizational readiness — performers, sequence of operations, completion deadlines, and installation date have been defined.

The combination of these elements reduces disorder in workshop operations and makes the production cycle more predictable.

2.3. Typical Causes of Downtime, Delays, and Rework

Downtime, delays, and rework are the main types of losses in the production and assembly cycle of custom metal structures [13]. Most often, they arise due to insufficient preparation of the project before moving on to the next stage.

Cause	Stage at Which It Arises	Result
Incomplete technical specification	Start of the project	Delays in design and approval
Inaccurate measurements	Collection of initial data	Errors in drawings and installation
Changes after approval	Design / production	Rework and schedule shifts
Lack of materials	Procurement / workshop	Production downtime
Unclear planning of operations	Workshop fabrication	Uneven workload across production areas
Lack of intermediate control	Production	Late detection of defects
Incomplete kitting	Before installation	Additional site visits and delayed handover
Unaccounted site conditions	Design / installation	On-site modifications

Source: Compiled by the author.

An analysis of these causes shows that most problems can be prevented even before active production begins [13]. This requires an incoming inspection of technical documentation, an assessment of the readiness of drawings, preliminary material procurement, checkpoints in the workshop, and preparation for assembly.

3. Author's Model for Optimizing the Production-and-Installation Process

The effectiveness of an individual project is determined not only by the quality of individual manufacturing operations, but also by the manageability of the entire production and installation process [2]. This process spans the entire journey from the initial technical specifications to the delivery of the finished structure to the customer.

The essence of the model is that a project should not move on to the next stage until the basic conditions of the previous stage have been met. Otherwise, uncertainty is carried forward—from the technical specifications to the design phase, from the design phase to the workshop, and from the workshop to installation [4]. As a result, the risks of downtime, rework, cost overruns, and missed deadlines increase.

Model Element	**Main Purpose**
Preliminary review of the technical specification	Verification of the completeness of initial data before the start of design
Readiness check before launch	Assessment of design, technological, and material readiness
Coordination between departments	Alignment of actions among the designer, workshop, procurement, and installation team
Unified order card	Recording key information in a single management document
Schedule-and-resource planning	Management of timelines, personnel, equipment, materials, and installation
Change management	Control of changes in drawings, materials, deadlines, and installation solutions

Source: Compiled by the author.

The main principle of the model can be stated as follows: an individual project should be flexible in terms of technical solutions but clearly managed in terms of the implementation process [12].

3.1. Preliminary Review of the Technical Specification and Initial Data

The first stage of optimization is an initial review of the technical specifications and input data. A project may seem clear at the level of a general description, but this is not sufficient for high-quality design, manufacturing, and installation [9].

The technical specifications should not only include the customer's preferences regarding the appearance or general dimensions of the structure [2]. They should also provide answers to key technical, manufacturing, and installation questions.

Data Block	**What Needs to Be Checked**
Product purpose	What the structure will be used for and what functions it must perform
Dimensions	Length, width, height, thickness, and permissible deviations
Materials	Type of metal, profile, sheet metal, stainless steel, fasteners, and components
Coating and finishing	Painting, powder coating, polishing, and anti-corrosion protection
Operating conditions	Outdoor or indoor use, humidity, temperature conditions, and loads
Installation site	Address, façade, fastening base, height, and access to the site
Logistics restrictions	Transportability, transportation dimensions, and packaging
Timelines	Desired completion date, installation date, and critical deadlines
Acceptance criteria	What is considered a completed and properly executed result

Source: Compiled by the author.

The result of such verification should be one of three statuses:

Status	Meaning
Ready for design	All key data have been collected, and development of the solution may begin
Requires clarification	Some data are incomplete or contradictory, and the launch is postponed until clarification is obtained
High-risk order	There are technical, material, or installation constraints that require separate approval

Source: Compiled by the author.

This approach prevents uncertainty from being carried over to the workshop [9] In steel manufacturing, this is particularly important, since an error at the beginning can result in the need to rework a structure that has already been welded, painted, or delivered.

3.2. Design, Technological, and Material Readiness of the Order for Launch into Production

Before submitting an individual project to the workshop, it is necessary to verify three aspects of readiness: design, process, and material [9]. If even one of these elements is incomplete, launching the project creates a risk of downtime, rework, or changes to design decisions during the manufacturing process.

Design readiness means having a complete set of drawings, specifications, and technical solutions [5]. The documentation must specify dimensions, materials, connection details, tolerances, coating type, fastening method, and other requirements.

Manufacturing feasibility means that the product can actually be manufactured under specific production conditions [16]. The design must be evaluated in terms of the sequence of operations: cutting, welding, assembly, grinding, painting, packaging, and transportation.

Material readiness for steel structures is a critical prerequisite for the smooth execution of work [17]. The absence of a single part—metal, a structural section, fasteners, paint, or components—can bring the entire cycle to a halt: the workshop waits for the material to arrive, the schedule is disrupted, the installation date is postponed, and the project becomes unmanageable [17].

Type of Readiness	What Is Checked	Result
Design readiness	Drawings, specification, joints, tolerances, coating, fasteners	The workshop understands exactly what needs to be fabricated
Technological readiness	Sequence of operations, equipment capabilities, labor intensity, assembly method	The product can be fabricated without unjustified interruptions
Material readiness	Metal, components, fasteners, paint, consumables, delivery timelines	The project is supplied with the resources needed for launch
Installation readiness	Site conditions, fastening method, access, installation date	The structure is fabricated with installation requirements taken into account

Source: Compiled by the author.

In practice, the rule is that a project is not sent to the workshop until its design, manufacturing, and material readiness have been confirmed [9].

3.3. Coordination Between the Designer, Workshop, and Installation Team

One of the main causes of delays is the loss of information between departments. A designer may prepare a technically sound solution but fail to take into account a specific manufacturing or installation detail. A manufacturing department may be able to produce a structure according to the drawings but without understanding the conditions under which it will be installed. The installation crew may receive the finished product but lack complete information about fasteners, the sequence of work, or the specifics of the site.

Therefore, in the author's model, coordination among the three main participants in the process occupies a key place:

designer → production workshop → installation team.

Before launching a complex project, it is advisable to hold a brief technical coordination meeting involving the designer, the shop foreman, the materials manager, a representative of the installation team, and the project manager [7]. In construction and installation processes, coordination between manufacturing, procurement, logistics, and installation reduces the risk of delays and improves coordination among project participants [25]. The goal of such coordination is to identify potential problems before they reach the production stage.

To avoid ambiguous accountability, an accountability matrix is used [12]. It specifies who is responsible for key decisions and control actions.

Management Issue	**Primary Responsible Party**	**Participants / Approving Parties**	**Result**
Completeness of the technical specification	Project manager or responsible manager	Designer, customer, installation team if necessary	The technical specification contains the required initial data
Approval of drawings	Designer and project manager	Customer, workshop supervisor, installation team for complex joints	Drawings are approved before launch
Material readiness	Person responsible for procurement / warehouse	Workshop supervisor, project manager	Materials are available or delivery dates are confirmed
Permission to launch in the workshop	Production manager or project manager	Designer, procurement, workshop supervisor	The project is ready for production
Completeness control	Workshop supervisor or quality officer	Installation team, warehouse	The product and all elements are ready for shipment
Transfer of information to the installation team	Project manager or installation manager	Designer, workshop supervisor	The team has the layout, fasteners, and site information
Recording changes and comments	Project manager	Designer, workshop supervisor, installation team	All changes are entered into the documentation and order card

Source: Compiled by the author.

This matrix prevents a situation where all participants in the process assume that a particular issue has already been checked by someone else. It also improves the consistency of information transfer between stages.

3.4. Unified Order Card as a Process Management Tool

To effectively manage an individual project, it is advisable to use a unified order form [10]. In the proposed model, it serves as the central management document, in which key information regarding technical, design, material, manufacturing, and installation readiness is recorded.

The card reduces reliance on verbal communication and provides a single-place view of the project's current status [10]. Specifically, it shows whether the drawings are ready, whether the materials specification has been finalized, whether a production start date has been set, what stage of manufacturing the product is in, who is responsible for quality control, whether the product is fully assembled before shipment, and what changes have been made during the process.

Unified Order Form

Field	Information / Status
Order number	No. _________
Order name / project site	_________________________________
Responsible designer	_________________________________
Drawing status	☐ in progress ☐ under approval ☐ approved ☐ requires changes
Material specification	☐ prepared ☐ checked ☐ materials reserved ☐ awaiting delivery
Production launch date	___ / ___ / ______
Fabrication stages	☐ cutting ☐ welding ☐ assembly ☐ finishing ☐ painting ☐ completion/kitting
Control points	☐ after cutting ☐ after welding ☐ before painting ☐ before shipment
Responsible workshop supervisor	_________________________________
Completeness status	☐ not complete ☐ partially complete ☐ fully ready
Shipment date	___ / ___ / ______
Responsible installation manager	_________________________________
List of comments and changes	1. _______________________________ 2. _______________________________ 3. _______________________________

The card should record not only planned data but also actual changes [10]. If changes to drawings, materials, deadlines, or installation conditions are not reflected in a single document, the workshop, the supply department, or the installation crew may be working with different versions of the information.

3.5. Schedule-and-Resource Planning and Order Dispatching

Optimizing the production and installation process is impossible without schedule and resource planning [12]. In the production of custom metal structures, it is not enough to simply set a target completion date for the product. It is necessary to understand what resources are required at each stage: personnel, equipment, materials, workspaces, transportation, an installation crew, lifting equipment, and time for painting or drying the coating.

Scheduling answers the question: When should each phase be completed?

Resource planning answers the question: Who will carry it out, using what equipment, and with what materials?

In practice, it's a good idea to categorize projects by status.

Status	Meaning
Awaiting clarification of the technical specification	Initial data are insufficient
In design	Technical solution is being prepared
Under approval	Drawings or conditions are awaiting confirmation
Materials in procurement	Resource supply is pending
Ready for launch	Drawings, materials, and work plan are available
In production	Workshop operations are being performed
Under quality control	Compliance with requirements is being checked
In painting/finishing	Final finishing is being performed
In completion/kitting	Parts, fasteners, and installation elements are being checked
Ready for installation	The product is fully prepared for dispatch to the site
Installed	Work has been completed on site
Closed	The project has been handed over, and comments have been recorded

Source: Compiled by the author.

Project management involves regularly monitoring the project's progress through these statuses [12]. This helps identify not only the overall timeline but also critical stages of the process where delays may occur: late preparation of drawings, lack of materials, overload at the welding station, delays in painting, or the installation crew or site not being ready [15].

The most effective approach is planning not according to the principle of "which order arrived first," but according to the level of readiness for execution [12]. A project that has a complete technical specification, approved drawings, available materials, and a clear installation logic should take priority over a project that formally arrived earlier but still contains uncertainty.

3.6. Change Management During Design, Fabrication, and Installation

In the manufacturing of custom metal structures, changes are almost inevitable. The client may specify different dimensions, change requirements regarding the appearance, or approve a different material or finish. Technical limitations may be identified during the design phase, and during installation, it may become necessary to adapt the design to the actual conditions at the site.

The problem lies not in the fact of changes themselves, but in how a company manages them. Uncontrolled adjustments lead to confusion in drawings, incorrect purchases, rework, schedule delays, and increased production costs [10]. Therefore, every change must be documented, evaluated, approved, and communicated to all participants in the process [10].

Type of Change	**Example**	**Potential Risk**	**Required Action**
Design-related	Change in a joint, dimension, or fastening method	Rework of parts, change in technology	Update the drawings and coordinate with the workshop
Material-related	Replacement of metal, profile, fasteners, or coating	Impact on strength, appearance, and delivery time	Check compliance and update the specification
Technological	Change in welding, finishing, or painting method	Change in labor intensity and quality	Coordinate with production
Installation-related	Change in access conditions, fastening base, or height	Additional work on site	Coordinate with the installation team
Schedule-related	Rescheduling of completion or installation date	Conflict with the schedule of other orders	Update the calendar plan
Commercial	Change in scope of work or customer requirements	Change in cost and budget	Approve the new execution terms

Source: Compiled by the author.

Only the most current version of drawings and specifications should be used in production. If outdated versions of the documentation remain in circulation, the risk of errors increases dramatically [10]. All changes must be tracked through version control: the date of the change, the person responsible, the nature of the change, who approved it, and to whom the updated information was forwarded.

4. Control Points and Performance Indicators

In the manufacturing and installation cycle of custom metal structures, quality control should be viewed not as a final inspection of the finished product, but as a system of interim decisions [9]. These decisions prevent a project from moving on to the next stage without confirmation that it is ready. The greatest losses occur when an error is discovered too late: after painting, before shipment, or even during on-site installation.

Checkpoints and KPIs are interrelated [12]. The former indicate whether a project is ready to move on to the next stage, while the latter show how effectively the management system itself is functioning.

4.1. Intermediate Quality Control at Key Fabrication Stages

In-process quality control is necessary to detect defects as they occur, rather than after the entire production cycle is complete [9]. This is particularly important for custom metal structures, since each product has its own geometry, materials, fasteners, and installation conditions [5].

Fabrication Stage	**What Is Controlled**	**What Problem This Prevents**
Cutting	Dimensions of parts, number of elements, marking	Geometry errors, shortage of parts, rework of blanks
Welding	Quality of welds, compliance with drawings, deformations	Structural defects, dimensional deviations, repeated welding

Assembly	Compatibility of elements, correctness of joints, compliance with installation logic	Problems during kitting and installation
Surface preparation	Cleaning, grinding, readiness for coating	Painting defects, poor-quality finishing
Painting/finishing	Coating quality, uniformity, compliance with requirements	Repainting, customer complaints, shipment delays
Before kitting	Compliance of the finished product with drawings and the technical specification	Transfer to installation of a product with undetected defects

Source: Compiled by the author.

The quality of the welds, compliance with the drawings, and any deformation must be checked during the welding stage [6]. These parameters directly affect the quality of the welded joints and the subsequent reliability of the structure.

After each inspection point, the project must be assigned one of three statuses:

Status	**Meaning**
Accepted	The product or work stage meets the requirements, and the process may proceed to the next stage
Requires rework	Minor deviations have been identified and must be corrected before the next stage
Transition blocked	A critical error has been identified that prevents continuation of the production cycle

Source: Compiled by the author.

This approach prevents defects from accumulating and reduces the cost of correcting them.

4.2. Completeness Control Before Logistics and Installation

A separate critical point is the completeness check before logistics and installation. A structure can be considered ready for installation only when the full set of the product, fasteners, auxiliary elements, installation information, and delivery conditions has been verified [9].

Control Object	**What Is Checked**
Main structure	Compliance with drawings, dimensions, and the technical specification
Individual parts and modules	Availability of all elements, marking, and compliance with the assembly scheme
Fasteners	Anchors, bolts, plates, brackets, and auxiliary installation elements
Coating / finishing	Absence of damage, scratches, painting defects, or polishing defects
Installation scheme	Current version of the scheme, installation sequence, and fastening specifics
Packaging	Protection of the product during transportation
Logistics	Delivery date, transport, loading and unloading method
Site readiness	Access to the installation location, readiness of the base, availability of equipment or permits

Source: Compiled by the author.

When verifying the readiness of the facility, access to the installation site, equipment, and permits, the requirements for safe work practices must be taken into account [11].

A project should not be marked as "ready for installation" until the foreman or supervisor confirms that all components are present and the person responsible for installation has received up-to-date information about the site. This reduces the risk of additional site visits, crew downtime, and delays in project completion.

4.3. Assessment of Timelines, Downtime, Rework, and Installation Risks

The assessment of a cycle's effectiveness must be tied to the actual problems that arise during project implementation [12]. It is not enough to simply note that the work was completed late or required rework. It is important to determine at which stage the problem arose, why it occurred, and what management tool should be used to prevent it in the future.

The assessment logic is based on the principle: **problem → optimization tool → KPI** [12].

Problem	**Optimization Tool**	**KPI**
Workshop downtime due to missing drawings	Preliminary review of the technical specification and readiness of design documentation	Share of orders launched without delay
Rework due to errors in drawings	Preliminary approval of design documentation	Number of reworks per order
Incomplete kitting before installation	Completeness control	Share of orders shipped without missing elements
Delay of the installation team	Coordinated production and installation schedule	Downtime of the installation team
Delay due to lack of materials	Verification of material readiness before launch	Share of orders with full material readiness
Changes after launch into production	Change management and control of the current drawing version	Number of changes after launch in the workshop
Damage or defects before shipment	Intermediate control after key operations	Share of defects detected before final finishing
Failure to meet the planned handover date	Schedule-and-resource planning and dispatching	Share of orders handed over on time

Source: Compiled by the author.

This approach prevents the formal use of KPIs. Indicators do not exist in isolation from the process—they demonstrate how effectively specific management decisions are working.

4.4. Use of KPIs to Analyze the Effectiveness of Optimization

In the proposed model, KPIs serve as a practical management tool [12]. They are intended to reflect not only the overall performance of the enterprise but also the effectiveness of specific decisions: input control of technical specifications, verification of design documentation readiness, material preparation, completeness checks, scheduling, and change management.

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The source of information for KPIs should not be a separate report prepared after the project is completed, but rather ongoing management tools: a unified work order, a change log, a schedule, milestones, and completeness status [1]. In this case, the metrics are not detached from the actual process but become a natural part of it.

The practical purpose of KPIs is that each metric should lead to a specific management decision. If workshop downtime increases due to a lack of drawings, it is necessary to strengthen incoming inspection of technical specifications and the readiness status of drawings. If the number of reworks is increasing, the procedure for approving technical documentation and conducting interim inspections should be reviewed. If incomplete orders occur frequently, control before shipment must be strengthened, and the foreman's accountability must be increased.

Therefore, checkpoints and performance metrics must function as a unified system. The former ensures the quality and readiness of the project at every stage, while the latter make it possible to assess the effectiveness of optimization in practical terms: less downtime, fewer reworks, fewer pre-installation deficiencies, fewer team delays, more precise adherence to deadlines, and better cost control.

5. Expected Results from Applying the Proposed Approach

The proposed approach to optimizing the production and installation cycle is aimed at improving the manageability of individual projects at all stages: from the formulation of technical specifications to the handover of the installed structure to the customer [4]. Its practical value lies not in completely eliminating all risks associated with non-standard production, but in making these risks visible, controllable, and manageable in a timely manner.

When the elements of the model work together systematically, the company benefits from a more predictable production and installation cycle, fewer downtimes and rework, better coordination between departments, and more consistent adherence to deadlines.

5.1. Generalized Example of a Production-and-Installation Project

To illustrate the application of the proposed approach, a generalized example of the fabrication and installation of a custom metal structure for a commercial facility may be considered. This may include a façade advertising structure, an architectural metal element, a frame for exterior design, a stainless-steel product, or another non-standard structure that requires not only workshop fabrication, but also delivery and installation at a specific site.

In the traditional approach, work often begins with an incomplete technical specification: the customer provides a general vision of the product, approximate dimensions, or a sketch, after which the designer prepares drawings, the workshop launches fabrication, and the installation team becomes involved only closer to the completion of the production stage [2]. This sequence creates the risk of late identification of important issues: unclear fastening conditions, unaccounted façade limitations, missing materials, transportation difficulties, or incomplete kitting before installation.

In the proposed model, the process is organized differently: before design begins, the technical specification undergoes preliminary review; the design documentation is checked with regard to manufacturability, resource availability, transportation, and installation logic [3]. Transfer to the workshop takes place only after design, technological, and material readiness have been confirmed.

Stage	**Action Within the Proposed Model**	**Expected Result**
Technical specification	Verification of initial data, installation conditions, materials, and deadlines	Fewer clarifications after the start of work
Design	Preparation of drawings with fabrication, transportation, and installation taken into account	Fewer technical errors
Material preparation	Preparation of the specification and verification of the availability of metal, fasteners, and coatings	Lower risk of workshop downtime

Launch into production	Transfer to the workshop after confirmation of design documentation and material readiness	More stable production schedule
Fabrication	Control after cutting, welding, finishing, and painting	Earlier detection of defects
Kitting/completion	Verification of the structure, parts, fasteners, and installation scheme	Fewer missing elements before installation
Logistics and installation	Coordination of delivery, site access, and work sequence	Less downtime for the installation team
Handover of completed work	Final verification of compliance with the technical specification	Higher-quality project completion

Source: Compiled by the author.

This example demonstrates that optimization is not limited to accelerating individual operations. Its main purpose is to make the entire project workflow consistent, transparent, and controlled.

5.2. Practical Results of Implementing the Proposed Approach

The practical results of applying the proposed model are reflected in several areas: reduced downtime, fewer reworks, improved preparation for installation, better cost control, and stronger interaction between departments [13].

Area of Improvement	How It Is Achieved	Practical Effect
Reduction of downtime	Preliminary review of the technical specification, readiness of design documentation, material preparation	Less waiting for drawings, materials, and approvals
Reduction of rework	Preliminary approval of design documentation, intermediate quality control	Earlier detection of errors
Improved quality	Control points at key stages	More stable compliance of the product with drawings and the technical specification
Improved installation	Completeness control, transfer of information to the installation team	Fewer additional site visits and delays
Better coordination	Responsibility matrix, unified order card	Less loss of information
Manageability of timelines	Schedule-and-resource planning and dispatching	More predictable schedule
Cost control	Recording of changes, rework, and downtime	Fewer unforeseen expenses

Source: Compiled by the author.

The proposed approach shifts the enterprise from reactive management, where problems are addressed only after they occur, to a proactive model [14]. In this model, risks are identified and controlled in advance.

5.3. Recommendations for Enterprises Working with Custom Metal Structures

Enterprises that manufacture custom metal structures in low- and medium-volume production should implement the proposed model gradually, starting with the most problematic stages of the cycle [13]. At the initial stage, it is sufficient to introduce clear rules for project flow, an order card, control points, and responsible persons.

Recommendation	Expected Effect
Preliminary review of the technical specification	Fewer clarifications after the start of work
Verification of design documentation readiness	Fewer errors in the workshop
Material preparation before launch	Less downtime due to missing materials
Unified order card	Greater process transparency
Responsibility matrix	Less ambiguity in responsibility
Intermediate control points	Earlier detection of defects
Coordination of production and installation	Less downtime for the installation team
Recording of changes	Less confusion with drawing versions and decisions
Post-project analysis	Continuous improvement of the process

Source: Compiled by the author.

5.4. Limitations of the Model's Application and Conditions for Its Effectiveness

The proposed model has a practical character; however, its application requires certain conditions. It is not a universal solution that automatically eliminates all production problems. Its effectiveness depends on how consistently the enterprise applies control procedures, records responsibility, and maintains execution discipline.

The model does not replace professional engineering design, proper calculations, high-quality design documentation, compliance with technological requirements, or safety requirements [11]. It also depends on the quality of the initial data: if the customer does not provide precise requirements, the site has not been inspected, installation conditions are unknown, and materials have not been defined, the system can only record the incompleteness of the data and prevent a premature launch.

Personnel discipline is an important condition. The unified order card, control points, responsibility matrix, and change log work only when employees actually use these tools [10]. If changes are communicated orally, drawings are not updated, and statuses are not recorded, the effectiveness of the model decreases.

Condition for Effectiveness	Meaning
Completeness of the technical specification	Provides the basis for design and production
Up-to-date design documentation	Ensures proper transfer of information to the workshop
Material readiness	Prevents downtime caused by missing materials
Clear responsibility	Reduces the risk of uncontrolled decisions

Intermediate quality control	Helps identify defects before the final stage
Coordinated production and installation schedule	Improves timeline predictability
Recording of changes	Prevents work from being performed based on outdated drawings
Post-project analysis	Helps improve subsequent orders

Source: Compiled by the author.

The proposed model is most effective for enterprises that are ready to move from situational management of custom orders to a systematic process-based approach. Its advantage lies in the fact that a significant part of the effect is achieved not through large-scale re-equipment of production, but through better work organization, documentation discipline, timely material preparation, clear responsibility, and regular control over the project workflow [1].

Conclusions

The article examined the problem of optimizing the production-and-installation cycle for custom metal structures in low- and medium-volume manufacturing. Based on practical analysis, it was established that the main difficulty in this field lies not only in the execution of individual technological operations, but in the organization of the entire project workflow: from the formulation of the technical specification to the handover of the installed structure to the customer.

Custom metal structures are highly variable in terms of dimensions, materials, fastening joints, finishing methods, transportation conditions, and installation requirements. For this reason, approaches typical of mass production cannot be fully transferred to low- and medium-volume manufacturing. In this field, it is impossible to fully standardize the product itself; however, the process of creating it can be standardized [1].

In the course of the study, the main causes of downtime, delays, and rework were identified: incomplete technical specifications, inaccurate initial data, insufficient detailing of design documentation, untimely material preparation, weak workshop planning, lack of intermediate quality control, incomplete kitting before installation, and unaccounted site conditions. Analysis of these causes shows that most problems arise at the interfaces between stages: between design and production, production and kitting, and kitting and installation.

The author's proposed optimization model is based on step-by-step verification of project readiness [2]. Its main elements are preliminary review of the technical specification, verification of design, technological, and material readiness, coordination among the designer, workshop, and installation team, use of a unified order card, schedule-and-resource planning, dispatching, and change management. Such a model prevents uncertainty from being carried over to subsequent stages and reduces the risk that errors will be detected only after fabrication or during installation.

The results obtained provide grounds for considering the proposed model as a process-based tool for managing the production-and-installation cycle of custom metal structures. Its specific feature is that control over the readiness of the technical specification, design documentation, material supply, product completeness, and installation logic is combined into a single system for managerial decision-making. As a result, the fabrication and installation of a custom metal structure are viewed not as a set of separate operations, but as an integrated, manageable process with clear conditions for transition between stages.

Material preparation is of particular importance. For metal structures, it is a critical condition for a stable production process, since the absence of metal, profiles, fasteners, paint, consumables, or components may stop the entire work cycle [17]. Therefore, launch into production should take place only after confirmation not only of drawing readiness, but also of actual or guaranteed material availability.

An important management tool is the unified order card. It records the project number, responsible designer, drawing status, material specification, production launch date, fabrication stages, control points, responsible workshop supervisor, completeness status, shipment date, responsible installation manager, as well as the list of comments and changes. As a result, the project is controlled not fragmentarily, but as a single production-and-installation process.

The performance indicators in the proposed model have a practical character and are directly connected with typical problems of the production cycle [12]. It is advisable to assess the share of orders launched without delay, the number of reworks per order, the share of shipments without missing elements, the downtime of the installation team, the level of material readiness on the launch date, the number of changes after transfer to the workshop, the share of projects handed over on time, and the deviation of actual cost from planned cost. Such KPIs function as feedback between real production problems and managerial decisions.

The expected results of applying the proposed approach include reduced workshop downtime, fewer reworks, improved quality of design and material preparation, lower installation risks, better interaction between departments, more accurate adherence to deadlines, and improved cost manageability. Importantly, a significant share of these results can be achieved not through large-scale re-equipment of production, but through better process organization, documentation discipline, allocation of responsibility, and regular control over the project workflow.

At the same time, the model has certain limitations. It does not replace professional engineering design, high-quality calculations, technological competence, or compliance with safety requirements [11]. Its effectiveness depends on the completeness of initial data, the relevance of design documentation, personnel discipline, timely recording of changes, and the enterprise's readiness to work according to a process-based approach.

Thus, optimization of the production-and-installation cycle for custom metal structures in low- and medium-volume manufacturing should be considered a comprehensive organizational and technological task. The most effective approach is one in which the individuality of the product is combined with a standardized, transparent, and controlled process for its creation. This is precisely the kind of model that helps enterprises working with non-standard metal structures improve the quality of work, reduce production losses, and strengthen their competitiveness within the industry.

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