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# System Analysis and Control
# Системный анализ и управление

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## METHOD FOR IMPLEMENTING SCHEDULING SYSTEMS IN DISCRETE-CONTINUOUS PRODUCTION: THE CASE OF OIL REFINERIES

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**Abstract.** This paper addresses the complex problem of production scheduling for continuous production facilities, such as oil refineries and petrochemical plants. The typical challenges of existing models are analyzed in detail, including the difficulty of accounting for all technological and logistic constraints, operational challenges, and the limited time available for schedule preparation and verification. As a solution, a five-step implementation methodology is proposed: 1) model aggregation to ensure solvability and accuracy, 2) selection of data updating methods (manual, semi-automated, or fully automated), 3) user adaptation through a structured planning process and automatic checks, 4) ensuring additivity between monthly plans based on linear programming and shift-daily schedules, and 5) automatic monitoring of plan and actual asynchrony to detect deviations. The methodology is embedded into the system implementation process, linking methodological principles with each project stage. It constitutes a replicable approach applicable to petrochemical and other continuous production facilities, ensuring the creation of a robust and adequate system capable of operating under the high dynamics and complexity of modern production.

**Keywords:** production scheduling, oil refinery, planning models, implementation methodology, APS

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# МЕТОД ВНЕДРЕНИЯ СИСТЕМ КАЛЕНДАРНОГО ПЛАНИРОВАНИЯ В ДИСКРЕТНО-НЕПРЕРЫВНЫХ ПРОИЗВОДСТВАХ: ПРИМЕР НПЗ

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**Аннотация.** В работе рассматривается комплексная задача календарного планирования непрерывных производств, таких как нефтеперерабатывающие и нефтехимические предприятия. Подробно анализируются характерные проблемы существующих моделей, включая сложность учета всех технологических и логистических ограничений, трудности эксплуатации и ограниченное время на подготовку и верификацию планов. В качестве решения предлагается методика внедрения из пяти шагов: 1) агрегирование модели для обеспечения ее разрешимости и точности, 2) выбор способов актуализации данных (ручной, автоматизированный, автоматический), 3) адаптация пользователей посредством структурированного процесса планирования и автоматических проверок, 4) обеспечение аддитивности между месячными планами на основе линейного программирования и сменно-суточными графиками, 5) автоматический контроль асинхронности плана и факта для выявления отклонений. Методика встроена в процесс внедрения системы, связывая методологические принципы с каждым этапом проекта, и представляет собой тиражируемый подход, применимый к нефтехимическим и другим непрерывным производствам и обеспечивающий создание устойчивой и адекватной системы, способной функционировать в условиях высокой динамики и сложности современного производства.

**Ключевые слова:** календарное планирование, нефтеперерабатывающий завод, модели планирования, метод внедрения, APS

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## Introduction

The efficiency of continuous production facilities, such as oil refineries and petrochemical plants, depends directly on the consistency of long-term volume planning, operational monthly plans, and shift-level production schedules. Significant financial losses, such as missed delivery deadlines, vessel demurrage, and non-optimal use of storage capacity, are caused by the inability to translate high-level plans into feasible, short-term schedules [1]. Despite the availability of commercial APS/MES solutions, implementations of production scheduling systems remain rare and often do not yield sustainable benefits [2].

The core difficulties are well known: models that fully capture all technological and logistic constraints become computationally intractable; manual updating of large volumes of input data consumes time that is simply not available for short-horizon rescheduling; coordinating models at several planning levels requires substantial manual effort; and plan vs actual analysis cannot be performed with the necessary frequency and depth.

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This paper presents a systematic method for implementing production scheduling systems that simultaneously addresses these problems. The method is structured around five interrelated principles:

1) aggregation,
2) actualization,
3) user adaptation,
4) additivity of plans,
5) asynchrony of plan vs actual.

Though the method is described for an oil refinery, it is designed for continuous and semi-continuous process industries in general.

Production scheduling in the process industries has been studied from several directions.

Approaches to the production scheduling problem are divided into deterministic and non-deterministic [3], employing both exact and heuristic solution methods

*Mathematical programming*

The dominant optimization approach is Mixed-Integer Linear Programming (MILP) [4]. MILP models can explicitly account for unit operating modes, tank capacities, and material quality constraints and have been extended to multi-product inventory logistics [5]. However, full-scale refinery models quickly become computationally intractable, which prevents their use for frequent, short-horizon rescheduling [4].

*Simulation*

Simulation models reproduce the dynamic behavior of production through rules and state changes [6] and have been employed for operational scheduling and plan vs actual analysis [7]. Among the main approaches to simulation modeling, one can distinguish the object-oriented approach, agent-based modeling, and distributed simulation [8]. The main drawback of simulation is the need for extensive manual control to find an acceptable schedule, making them time-consuming for daily use.

*Decomposition and aggregation*

To manage complexity, decomposition-coordination methods divide the plant-wide problem into sub-problems by production stages [9]. Aggregation techniques reduce model dimensionality by simplifying resources and time scales [10]. While computationally effective, these approaches introduce the problem of ensuring consistency and feedback between the sub-models and the original problem.

*Heuristic methods*

Rule-based and metaheuristic algorithms can find acceptable solutions quickly [11], but they sacrifice optimality and require significant tuning by experienced users.

The analysis reveals that existing approaches treat individual aspects of the scheduling problem in isolation – model formulation, algorithm, or data integration. While comprehensive reviews and integrated views on scheduling models and tools exist [12], no holistic implementation methodology has been proposed that simultaneously addresses the choice of model granularity, automation of data actualization, coordination of multiple planning levels, and operational control of plan vs actual deviations. This gap is the starting point of the present work.

***Planning models issues***

Despite numerous scientific works devoted to production scheduling tasks and the availability of commercial products created to solve these tasks, current implementations of scheduling systems for oil refining productions are rare. Analysis of the features of models and planning systems, data sources, as well as the implementation process at refineries, reveals a number of issues with existing approaches to this task.

*Issue 1. The model does not account for all constraints*

Sequential Linear Programming (SLP) methods, used in modeling systems such as PIMS by AspenTech[1], RPMS by Honeywell[2], Plan by Nauka LLC[3], and Production Modeling System for Oil Refining and Petrochemistry (SMPR) by Centre of Digital Technologies LLC [13], excellently solve the task of monthly volumetric planning for oil refining production considering flow quality indicators, but are not applicable for the production scheduling task, as the models of these systems do not account for logistical constraints (tank farms, loading racks). Therefore, to account for these constraints, it is necessary to use other models and solution methods.

*Issue 2. The model is difficult to use*

Simple mathematical planning models may not account for all necessary constraints. For example, using a simple tabular simulation model created in MS Excel, one can easily create a schedule for petroleum product shipments with daily detail, but the capacities of loading racks, the operation of tanks and events lasting less than a day will not be accounted for.

When using complex mathematical models and methods, e.g., optimization MILP models or heuristic methods, problems arise with their configuration to obtain a solution, the input of additional constraints necessary to account for features that emerged after the model was put into operation, as well as the problem of interpreting and analyzing the obtained solution.

After analyzing the obtained solution, a need for its adjustment may arise because either the model does not account for all constraints, or the user possesses knowledge about upcoming events that are unavailable to the model as source data. For example, the priority of producing a certain product, a decrease in unit capacity, or the need to empty a tank below the minimum inventory level. In such a case, the user must either add a constraint to the model or manually correct the obtained solution. When using an optimization model, introducing an additional constraint can lead to a change in the solution over the entire planning horizon or to an infeasible solution. Consequently, the need for re-analysis of the obtained plan or schedule arises. This necessity also arises when using other models and methods.

*Issue 3. Limited time for schedule preparation*

Planning department employees can spend from one day to a week preparing the monthly volume plan. The preparation process occurs before the start of the planning period, for example, by the 25th of the month preceding the planning period. The monthly production plan undergoes approval and endorsement in several divisions of the plant and the oil company. The calculation of the plan itself using an optimization model takes no more than 5 minutes; however, the preparation of source data, model actualization, analysis of results, and plan coordination take significant time.

Significantly less time is allocated for the preparation of the production schedule. For example, a production schedule with a 24-hour planning period cannot take more than one day to prepare; a schedule with a one-shift planning period cannot take more than one shift; and a plan with a one-hour planning period cannot take more than one hour. Thus, the time for preparing and verifying source data, calculating, and analyzing the obtained results is limited.

When preparing data for calculation using a production scheduling model, data from other models are used, for example, from current planning models and balance models, as well as from various source data systems (Fig. 1).

[1] AspenTech | Process Engineering, Asset Performance Management, Digital Grid Management AI Software | Industrial Digital Transformation, Available: http://aspentech.com/ (Accessed 14.11.2025).

[2] Process Automation | Honeywell, Available: https://process.honeywell.com/ (Accessed 14.11.2025).

[3] IT-kompaniia NAUKA – tsifrovizatsiia protsessov i proizvodstv [IT company NAUKA – digitalization of processes and production], Available: https://ntik.ru/ (Accessed 14.11.2025).

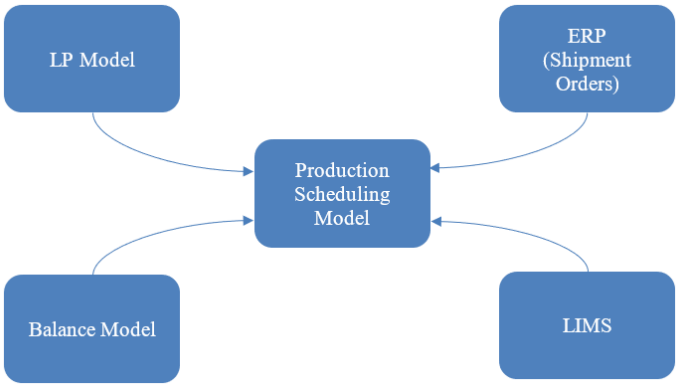



Fig. 1. Interaction of the production scheduling model with other models and data sources

Time during source data preparation can be spent not only on forming the conditions for solving the problem but also on detecting and correcting discrepancies between the production scheduling model and the source models/systems. Thus, a new stream in the LP model, not accounted for in the production scheduling model, can lead to an inadequate production schedule.

When using several models with different time scale, the task of correlating the obtained results for nested time intervals arises. The solution of the monthly planning model does not contain instructions on how and in which period to implement the monthly assignments. Similarly, a production schedule with a daily planning period does not specify how production should function within a day. At the same time, the solution of the monthly planning model contains source data for production scheduling models.

*Issue 4. Interrelation of planning models*

Solving the production scheduling task as a whole for the entire production with the required detail (in terms of days/shifts, hours/minutes/events) does not seem feasible. For mathematical programming methods, the difficulty lies in the high dimensionality of the models. Simulation modeling methods require a large amount of manual control to find a solution. Heuristic methods do not guarantee achieving an optimal solution. Therefore, the planning task is divided into parts – production stages, for example, feedstock receipt, primary and secondary processing, blending and packaging of finished products, product shipment (Fig. 2).

The process of decomposition into subtasks can be performed not only in terms of parts of the production but also in terms of time (planning horizon, time discretization) and the detail level of production parts (accounting for part of the technological constraints).

When using several models for different parts of the production or with different detail levels according to the technological scheme, it is necessary to consider the interrelation of these models (Fig. 3), and hence the systems ensuring their construction, data population, solution, analysis, and output of results.

Violation of the interrelation of models causes erroneous calculations: operating conditions, as well as the production itself, can change, and therefore the models of this production must change. If model changes occur uncoordinatedly, the solution of the production scheduling task ceases to be adequate.

*Issue 5. Plan-vs-actual analysis*

The actual operation of production should correspond to the calculations produced using planning models, i.e., the actual should be close to the plan, which is verified by their comparison. When using several models that solve the planning task for different production areas or with different detail, comparing their calculation results with the actual remains relevant but is complicated by the large

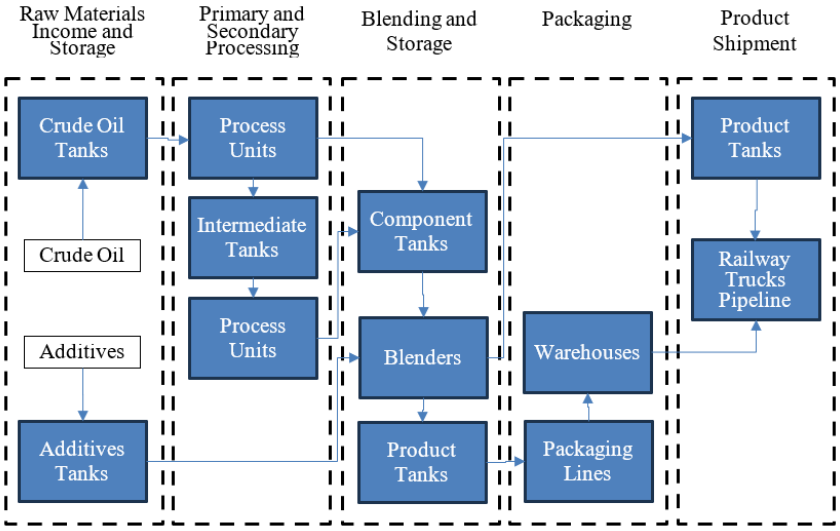



Fig. 2. Example of dividing refinery production into stages

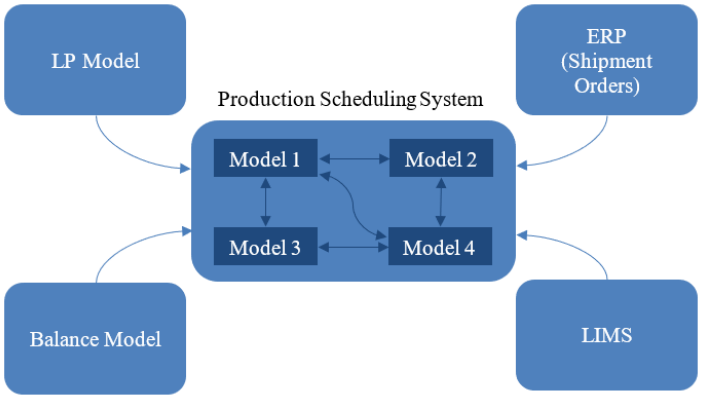



Fig. 3. Interaction of production scheduling models with each other, with other models and data sources

number of compared parameters and the limited time necessary for conducting the plan-vs-actual analysis and making a decision on plan adjustment.

The above list of problems must be taken into account when optimizing the work processes of production scheduling at a refinery, namely when choosing a production scheduling system and the process of its implementation (methodology).

## Proposed method

The proposed method consists of five steps, briefly outlined in [14], that must be performed jointly. Each step corresponds to a principle derived from the issues identified in previous section.

***Step 1. Model aggregation***

A planning model is a description of a technological object, with the help of which one can answer the question of how this object will operate in the future. The model consists of elements of the technological object, such as units, tanks, pipelines, etc. It must account for the parameters of these elements, for example, capacity constraints, volume, flow rate, etc. Furthermore, the model uses for planning a set of source data that establishes the correspondence of the model elements with the

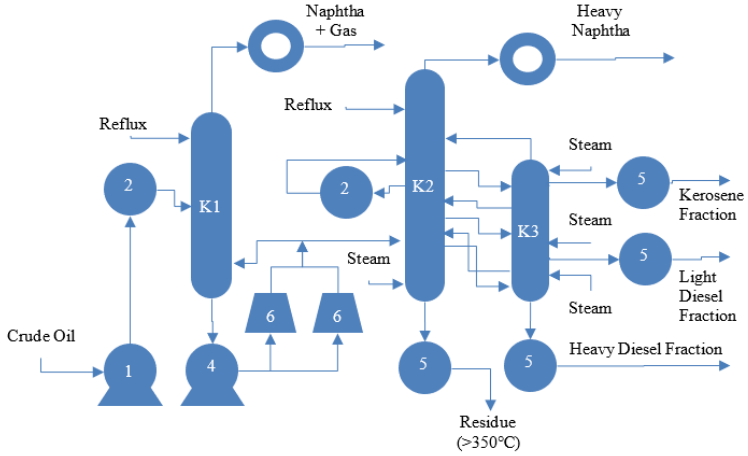



Fig. 4.1. Detailed model of a CDU: 1) crude oil pump; 2) heat exchangers; 3) condensers-coolers; 4) hot pump; 5) chillers; 6) furnaces; K1–3 – distillation columns

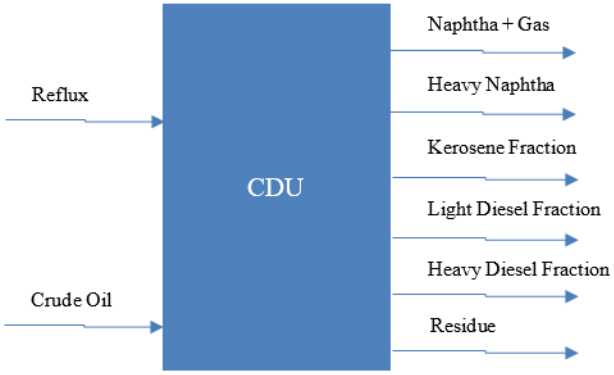



Fig. 4.2. Simplified model of a CDU

current (tank inventories) and target (shipment plan) state of the technological object. Thus, we can speak of three components of the model:

1) element description,
2) parameters,
3) source data.

The same technological object can be described by models of different detail levels.

Firstly, the level of detail is set by the number of elements used to model a particular technological object. For example, an atmospheric-vacuum Crude Distillation Unit (CDU), consisting of pumps, heat exchangers, coolers, furnaces, and columns, can be represented as a single model element with incoming and outgoing petroleum product streams (Fig. 4.1). If the goal is to obtain a plan for this unit's operation requiring forecasting of product output depending on feedstock properties and capacity, there is no need to consider its technological device, and the chosen level of aggregation allows simplifying the model (Fig. 4.2).

Secondly, the number of parameters and constraints related to a single element also determines the model's granularity. To schedule tank farm operations, it is necessary to consider minimum and maximum tank inventory constraints. Additionally, there could be a requirement for the model to consider

the desired minimum and maximum inventory level. Such constraints will increase the complexity of the planning model but also will allow more accurate schedule.

Thirdly, the number of parameters and input data required for a model's validity depends on the number of elements. For example, a model for a 20-tank tank farm requires twice as much data on tank constraints and initial conditions as a 10-tank farm.

*Overview of step 1*

The level of detail of the scheduling model is chosen based on two criteria: the accuracy required for decision-making and the computational time acceptable for the given rescheduling frequency. Aggregation refers to the number of modeled elements (e.g., representing an entire crude distillation unit as a single node with input/output streams vs detailed flowsheet) and the set of constraints (e.g., hard capacity limits only vs additional desired inventory bands). The chosen level of aggregation directly determines the feasibility of subsequent automatic actualization and user interaction.

***Step 2. Data actualization***

Actualization means bringing the model into conformity with the current production situation. The model's parts are updated with different frequencies: model elements and their parameters change rather rarely, typically during modernization, repair, or commissioning of new production facilities; source data for calculation, on the contrary, change frequently.

Manual, fully automated, or semi-automated – these are methods of model actualization in consideration.

With the manual method, the user makes the necessary changes to the model using the graphical interface of the planning system. The manual actualization method is characterized by high time consumption, proportional to the model's detail (see aggregation level), as well as a high probability of errors when making changes to the planning model, setting parameters, and entering source data.

The fully automated method involves configuring the information system services so that changes to the planning model are made without user, for example, based on changes in an external application's database or by automatically importing a file with the necessary data. With the fully automated actualization method, it is necessary to establish a relationship between the planning model and data sources and have data integration and validation tools.

The semi-automated method is intermediate between manual and fully automated ones, as it requires the user participation, for example, to select only specific data for import, put additional information to this data, or manually specify the correspondence between the data source and a model element.

An information system that actualizes the model can update the model's components using various methods, presented in Table 1.

Table 1

**Example of planning model actualization methods**

| Model Components | Actualization Method | | |
|---|---|---|---|
| | Manual | Fully Automated | Semi-automated |
| Element's description | ✓ | | |
| Element's parameters | ✓ | | |
| Tank Source Data | | ✓ | |
| Quality Source Data | | | ✓ |
| Order Source Data | ✓ | | |

The interrelation of the aggregation level with the choice of actualization method can be demonstrated by the following example. Let a planning model have a parameter specifying the minimum oil product level in a tank. A period in which the oil product level in the tank is below the minimum contains non-zero penalty variables, indicating a violation of this constraint, and the solution is considered inadequate. However, after the completion of scheduled tank maintenance, the inventory in it is less than the constraint set in the model, which leads to the appearance of non-zero penalty values. Eliminating the presence of non-zero penalties in this situation can be achieved in various ways:

1. One can modify the planning model so it will take into account the possibility of violating the minimum tank inventory constraint after coming out of scheduled maintenance. This will affect the model's level of detail and complicate its structure.

2. The planning model remains unchanged, but an actualization method is created where the parameter specifying the minimum tank inventory will be zero or equal to the residue in the tank after the completion of maintenance. In this case, it is necessary to calculate or estimate the time it will take for the tank to fill to the minimum level in order to restore the real constraint value.

The second option can be implemented with fully automated and semi-automated methods of actualizing source data and model parameters. With the manual actualization method, this option would require significant time from the model user and could be a source of model configuration errors if the user does not return the constraint value to its original state.

When choosing a method for actualizing source data, the frequency of calculation using the model is decisive: when calculating once a month/week, there is enough time for the manual actualization method; when calculating once a day/hour and with a large volume of data, there will not be enough time for manual data update, validation, and entry into the model. Thus, to use the manual method of source data actualization, it is necessary either to reduce their volume, i.e., aggregate the model (see aggregation level), which will entail a decrease in the adequacy of the obtained plans, or to perform calculations less frequently (once a week), which will entail an increase in reaction time to changes in the production situation and reduce planning efficiency. Fully automated and semi-automated actualization methods solve these problems; however, they require establishing relationships between data sources and the planning model and using integration tools.

*Overview of step 2*

For each component of the model (structure, parameters, initial data etc.) a concrete method of update (manual, fully automated, and semi-automated) is fixed according to the frequency of change and the available integration infrastructure. For example, laboratory quality data are updated automatically from LIMS, while the activation of a new process unit is entered manually. The decision is critical: with shift- or hour-level rescheduling, manual data entry becomes impossible without sacrificing timing or accuracy. Fully automated and semi-automated actualization eliminates this bottleneck and prevents configuration errors caused by missed or delayed updates.

***Step 3. User adaptation***

As with the implementation of any complex information system, users are main reasons of the success or failure of the project. The adoption of the system, as well as new workflows, also depends on the system's users.

On the one hand, users can undergo formal training on the use of the system and new workflows, in the form of a user course, and gain an understanding of how to use the scheduling system for their daily tasks. However, it is worth noting that although this approach will allow the system to be handed over for industrial operation and used successfully for some time after commissioning, it does not guarantee the maintenance of a lasting effect from the implementation of the new information system.

On the other hand, the participation of key end users in the project implementation process, undergoing in-depth training in the form of a series of advanced user courses, will allow them to view the system not as a "black box", but as a flexible tool for performing and optimizing daily work tasks.

At the same time, the topics of advanced training must include model creation, mathematical aspects of finding a solution, configuration, and system support. This approach requires a certain level of training from the users.

Regarding the optimization of business processes, in addition to the requirements for the level of training of end users at the time of handing over the system for trial operation, it is also necessary to consider the degradation of user knowledge over time, or the complete disappearance of this knowledge when team members change, which happens quite often due to promotions of planning department employees or staff turnover.

Furthermore, training materials, courses, and user support materials must be updated with product updates, and this imposes certain requirements on the software vendor.

The level of detail of the planning workflow, which is the result of optimization/re-engineering of scheduling business processes, is directly related to the user and their level of mastery of the system. The planning workflow must be sufficiently detailed, but not overloaded, so that it can be comprehended. The aggregation level and the model actualization method directly influence the level of detail of the planning workflow, which, in turn, affects the efficiency of using the implemented planning system.

*Overview of step 3*

The planning workflow and system interface are designed so that the user perceives the system as a transparent decision-support instrument, not as a "black box". The workflow must be sufficiently detailed to reflect the actual work of the planning department but not overloaded. Special attention is paid to the degradation of user knowledge over time and during staff rotation; therefore, the workflow is reinforced by automated validation checks that prevent typical human errors.

***Step 4. Additivity of plans***

Additivity is a property of quantities, consisting in the fact that the value of a quantity corresponding to a whole object is equal to the sum of the values of the quantities corresponding to its parts.

Planning is always conducted at several levels. Starting from investment plans for several years and ending with hourly schedules or event-based periods. The planning workflow, which is the result of optimization/re-engineering of planning business processes, is responsible for the sequence of actions during planning, the identification of stakeholders, and data flows in planning.

The planning workflow must consider the sequence of plan calculations, and this means the interaction of several plans, when the results of one are the source data for the calculation of another, and then the results of the second adjust the first, thus establishing feedback. The interaction of plans is the interaction of several systems (and/or their models) of different planning levels, or of one model, but calculated for different source data (which is quite rare). At the same time, the workflow must consider the detail level of the models, the method of actualization, and user adaptation.

*Overview of step 4*

Consistency between the results of models at different planning levels is enforced procedurally and mathematically. The monthly LP plan serves as a set of target volumes for the scheduling model, while the schedule, once calculated, provides feedback on the achievability of those targets. This creates a closed-loop management cycle and eliminates the situation where the schedule contradicts the monthly plan.

***Step 5. Asynchrony of plan and actual***

Planning is a corrective process, so it is necessary to know the current state, the target state, the deviation, and, moreover, to respond appropriately to identified deviations. The planning system must automatically account for the plan deviation from the actual, considering the actualization method: perform data collection, comparison, analysis, and presentation of results in the form of reports or recommendations. Report generation must satisfy the principle of user adaptation, and recommendations for adjustment must satisfy the principle of plan additivity. In addition, actual data on the

production state may come from systems that have a different object detail, which establishes a connection with the aggregation principle.

*Overview of step 5*

A mechanism for the automatic detection of deviations is built into the system. Scheduled and actual inventories, material movements, and shipments are compared at every calculation cycle. Discrepancies are visualized, and rule-based recommendations for plan adjustments are generated. This automates the labor-intensive plan-vs-actual analysis and guarantees that the schedule remains relevant under changing production conditions.

***Advantages of the proposed method***

The five-step method provides several measurable and qualitative advantages over conventional, isolated implementation approaches. A comparative summary is given in Table 2.

Table 2

**Comparison of approaches**

| Criterion | MILP | Standalone Simulation | Decomposition | Proposed Method |
|---|---|---|---|---|
| Solvability for large problems | Low | High (manual search) | Medium | High (guided aggregation) |
| Schedule preparation time | Long | Long | Medium | Short (automated actualization) |
| User expertise required | Very high | Medium | High | Medium (structured workflow) |
| Cross-model consistency | Low | Low | Medium | High (additivity principle) |
| Plan-vs-actual analysis | Manual | Semi-automated | Manual | Automated (asynchrony) |

Quantitatively, pilot applications at a refinery site showed a reduction in schedule preparation time from approximately eight hours to three to four hours, and the elimination of data transfer errors between the monthly plan and the daily schedule. The key qualitative advantage is the creation of a single, consistent version of the production plan across all management levels, which is automatically maintained over time through the principles of actualization and asynchrony.

**Implementation framework**

The implementation of a production scheduling system is carried out similarly to the implementation of any information system for production automation, and both agile methods, the waterfall approach, and a hybrid approach can be applied [15]. The stage-wise sequence presented below corresponds to the classic process of creating automated systems, regulated by GOST 34.601-90 “Automated systems. Stages of development” or ISO/IEC 12207 “Systems and software engineering – Software life cycle processes”. The project stages when implementing the waterfall and hybrid approach are the following:

1. Site survey and technical requirements development.
2. System design.
3. Development and actualization of production scheduling models.
4. Model testing of the system.
5. System deployment on site.
6. System integration.
7. User training.
8. Trial operation.
9. Model adjustment and handover of the system for industrial operation.

When implementing a hybrid approach, stages 1–9 can be carried out iteratively and only for a specific functionality of the system being developed in a sprint.

*At the first stage*, a survey of the refinery is carried out, during which the production technology, available documentation, technological parameters, statistical data on equipment loading, production volumes, feedstock supply, and product shipment are studied. Data on laboratory operations are also collected. Information is gathered about the plant's information systems that are sources and consumers of data for the planning system. Also, during the first stage, the technical requirements for the system are developed and approved, detailed based on the survey results.

*At the second stage*, system design is carried out, during which a technical (or preliminary) design is developed. The technical design includes the system architecture, component interaction diagrams, integration interfaces with other systems, and specifications of equipment and software. The preliminary design contains preliminary solutions and concepts that are detailed in the technical design. At this stage, the planning workflow is also developed.

*At the third stage*, based on the approved design solutions, the development and actualization of production scheduling models are carried out. The models are populated with data, parameterized, and configured in accordance with the plant's technological processes.

*At the fourth stage*, model testing of the system is conducted. Testing is performed on an isolated stand using actual and planned data to verify the correctness of calculations, the adequacy of the models, and the functionality of the planning algorithms.

*At the fifth stage*, the system is deployed at the plant site. Server and client software are installed and configured, databases are deployed, and the infrastructure is prepared.

*At the sixth stage*, work is carried out to integrate the production scheduling system with other enterprise systems (e.g., ERP, MES, LIMS), which are sources and consumers of data. Automated information exchange flows are configured.

*At the seventh stage*, users are trained to work with the system, configure it, update existing planning models, and create new models.

*At the eighth stage*, the system is handed over for trial operation. At the plant, the adequacy of the production scheduling models under real conditions is checked, software and model errors are identified, and requirements for additional reports and functionality are formed.

*At the ninth stage*, based on the results of trial operation, the system's models and software are adjusted, necessary reports are created, and documentation, including the planning workflow, is updated. After eliminating all identified problems and successfully completing acceptance tests, the system is handed over for industrial operation.

The nine-stage implementation process is not a mere project plan but the operationalization of the five-step method. The Aggregation level is formalized during Site Survey and Design. The Actualization method is configured during Integration. User Adaptation is realized through training and trial operation. Additivity and Asynchrony are embedded as functional requirements during System Design and are validated during Model Testing and Trial Operation. This explicit link between the methodological principles and the project stages distinguishes the approach from conventional system deployments and is the critical factor for long-term sustainability.

## Conclusion

The analysis presented in this paper revealed that existing approaches to production scheduling fail in industrial practice not because of model inaccuracy, but because of the absence of a holistic implementation methodology that simultaneously addresses model aggregation, data actualization, plan consistency, and user involvement.

The main result of the work is a novel five-step implementation method (aggregation, actualization, user adaptation, additivity, asynchrony) that systematically guides the design, deployment, and

operation of a scheduling system. Unlike previous works that focus on isolated algorithmic performance, this method ensures the system's viability in a real production environment.

Application of the method led to a reduction of schedule preparation time by approximately 40%, complete elimination of errors caused by manual data transfer between planning levels, and the creation of a single, synchronized planning cycle. The method provides a replicable framework that is currently being extended to other continuous process industries, confirming its generality beyond oil refining.

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