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5.4. Intelligent planning and production dispatching

5.4.1. Theoretical and methodological principles of intelligent production planning.

Intelligent production planning should be considered not as a separate software module, but as a holistic management concept, within which a manufacturing enterprise moves from periodic compilation of static schedules to continuous analysis of the state of resources, orders, material flows and risks. In the traditional approach, the plan was often fixed for a certain calendar period and changed only after a significant deviation, while the modern environment requires constant readiness for restructuring. Such an environment is characterized by shorter product life cycles, an increase in the share of individual orders, instability of supply, complexity of technological routes and the need to simultaneously control cost, quality, deadlines and flexibility. That is why planning can no longer be just an administrative procedure; it becomes a tool for the strategic sustainability of the enterprise [3].

The concept of intelligence in planning means the ability of the system not only to process given standards, but also to detect hidden patterns, predict future deviations, compare alternative scenarios and explain the consequences of management decisions. Unlike conventional automated calculation, an intelligent system must take into account the incompleteness and variability of information, since production rarely operates under conditions of complete certainty. For example, the duration of an operation may depend on the actual state of the equipment, operator qualifications, properties of the batch of material, the need for readjustment and the current load of adjacent sections. Classical scheduling theories provide a formal apparatus for describing such problems, but real practice requires supplementing these models with heuristics, data and expert knowledge [1].

Methodologically, intelligent planning is based on a combination of a systems approach, the theory of constraints, operations management, mathematical optimization, and artificial intelligence. The systems approach allows us to see an enterprise as a network of interconnected processes, in which local improvement does not always give a general effect. The theory of constraints directs attention to bottlenecks, that is, resources or processes that determine the throughput of the entire system. Operations management forms the rules for coordinating demand, capacity, and inventory. Mathematical optimization allows us to calculate acceptable or optimal schedules, and artificial intelligence expands the possibilities of forecasting and adaptation. Such a synthesis is especially important for enterprises where high variability of orders is combined with limited resources and high cost of error [4].

5.4.1.1.1. The essence of the production plan.

Within the topic of “the essence of the production plan”, the production plan acquires special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an implemented sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach lies in the fact that it ensures the coordination of demand, capacities and material resources, and does not simply create another document for administrative control. If the system ignores errors in the initial data, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not an agreed digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [1], [3].

From the perspective of production management, the essence of the production plan cannot be assessed in isolation from other elements of the system. Even if the production plan is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the coordination of demand, capacities and material resources becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it does not exacerbate errors in the initial data. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [1], [3].

5.4.1.1.2. Planning hierarchy.

Within the topic of "planning hierarchy", the strategic, tactical and operational levels are of particular importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an implemented sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the transformation of long-term goals into shift-daily tasks, and does not simply create another document for administrative control. If the system ignores the gap between the sales plan and the shop reality, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [3].

From the perspective of production management, the planning hierarchy cannot be evaluated in isolation from other elements of the system. Even if the strategic, tactical and operational levels are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the transformation of long-term goals into shift-daily tasks becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it increases the gap between the sales plan and shop reality. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [3].

5.4.1.1.3. Dynamics of the production environment.

Within the topic of “dynamics of the production environment”, the current state of equipment, personnel and materials acquires special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the adaptation of schedules to events, and does not simply create another document for administrative control. If the system ignores delays, accidents and changes in priorities, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [2], [4].

From the perspective of production management, the dynamics of the production environment cannot be assessed in isolation from other elements of the system. Even if the current state of equipment, personnel and materials is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the adaptation of schedules to events becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it increases delays, accidents and changes in priorities. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [2], [4].

5.4.1.1.4. The concept of optimality.

Within the topic of "the concept of optimality", the criteria of deadlines, costs, loading and stocks acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into a performed sequence of actions. For the planner, it is important to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the search for a balance between conflicting goals, and does not simply create another document for administrative control. If the system ignores a one-dimensional assessment of efficiency, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [1].

From the point of view of production management, the concept of optimality cannot be assessed in isolation from other elements of the system. Even if the criteria of deadlines, costs, loading and stocks are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why finding a balance between conflicting goals becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether it does not strengthen the one-dimensional assessment of efficiency. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [1].

5.4.1.1.5. The role of standards.

Within the topic of “the role of standards”, technological routes, time standards and specifications acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an implemented sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the formation of a reliable production model, and not simply creates another document for administrative control. If the system ignores outdated or averaged standards, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than an agreed digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [3], [4].

From the point of view of production management, the role of standards cannot be assessed in isolation from other elements of the system. Even if technological routes, time standards and specifications are described in sufficient detail, their impact on the result depends on how they interact with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the formation of a reliable production model becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether it reinforces outdated or averaged standards. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [3], [4].

5.4.1.1.6. Bottlenecks.

Within the topic of “bottlenecks”, resources that limit throughput are of particular importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides concentration of managerial attention, and does not simply create another document for administrative control. If the system ignores the optimization of non-critical operations, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [4].

From the perspective of production management, bottlenecks cannot be assessed in isolation from other elements of the system. Even if the resources that limit throughput are described in sufficient detail, their impact on the result depends on how they interact with shift calendars, work queues, material availability, equipment condition, and customer order priorities. An intelligent system must not only capture this interaction, but also show what consequences each management decision will have. That is why the concentration of management attention becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it enhances the optimization of non-critical operations. In complex production, local optimization can create hidden losses in adjacent areas, increase work-in-progress, or worsen the fulfillment of deadlines [4].

5.4.1.1.7. Planning under uncertainty.

Within the topic of “planning under uncertainty”, probabilistic scenarios and time reserves are of particular importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an implemented sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it reduces the risk of order disruption, and does not simply create another document for administrative control. If the system ignores the ignoring of variability, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [4], [5].

From the perspective of production management, planning under uncertainty cannot be assessed in isolation from other elements of the system. Even if probabilistic scenarios and time reserves are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why reducing the risk of order disruption becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether it does not increase the ignoring of variability. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [4], [5].

5.4.1.1.8. Explainability of decisions.

Within the topic of "explainability of decisions", the logic of the system's recommendations becomes of particular importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the trust of planners and dispatchers, and does not simply create another document for administrative control. If the system ignores the opacity of algorithms, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [5].

From the perspective of production management, the explainability of decisions cannot be assessed in isolation from other elements of the system. Even if the logic of the system's recommendations is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, equipment condition, and customer order priorities. An intelligent system must not only capture this interaction, but also show what consequences each management decision will have. That is why the trust of planners and dispatchers becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it increases the opacity of algorithms. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress, or worsen the fulfillment of deadlines [5].

5.4.2. Methods, models, algorithms and data in intelligent planning.

Intelligent planning is impossible without a clear understanding of what models and algorithms are used to describe production reality. Any algorithm does not work with the physical shop directly, but with its formalized representation: a list of jobs, operations, resources, calendars, constraints, priorities and criteria. If such a model is too simplified, the system generates schedules that look correct in the program, but cannot be executed in practice. If the model is too complex, it is difficult to maintain, and the calculation time may exceed acceptable limits. Therefore, the main task is to find a methodical balance between accuracy, controllability and speed. This is the difference between applied production planning and abstract mathematical modeling [1].

Data in an intelligent system is not auxiliary, but decisive. Even the best algorithm cannot form a quality plan if the system does not know the actual remains of materials, availability of equipment, staff turnover, real time standards or technological alternatives. Often, implementation problems are explained not by software shortcomings, but by the fact that the enterprise has accumulated inconsistent directories, duplicate positions, incomplete routes, outdated norms and informal rules that exist only in the memory of individual employees for years. Intelligent planning requires converting this knowledge into structured data that is available for calculation, control and verification [3].

Artificial intelligence methods in production planning are appropriate to use where classical deterministic approaches do not provide sufficient accuracy or flexibility. Machine learning can predict the duration of operations, the probability of defects, the risk of delay, and the condition of equipment. Heuristic algorithms can quickly generate acceptable schedules for large production systems. Simulation modeling allows you to assess the consequences of management actions before they are implemented. Fuzzy logic helps to work with qualitative estimates, and agent models describe the interaction of autonomous resources. At the same time, artificial intelligence should be included in a responsible management procedure, and not used as an uncontrolled black box [5].

5.4.2.2.1. Mathematical formulation of the problem.

Within the topic of "mathematical problem formulation", work, operations, machines and constraints acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach lies in the fact that it ensures the transformation of the production situation into a schedule model, and not simply creates another document for administrative control. If the system ignores the wrong choice of criterion, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [1], [2].

From the perspective of production management, the mathematical formulation of the problem cannot be evaluated in isolation from other elements of the system. Even if the jobs, operations, machines and constraints are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the transformation of the production situation into a schedule model becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it does not reinforce the wrong choice of criterion. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [1], [2].

5.4.2.2.2. Heuristic rules.

Within the topic of “heuristic rules”, priority rules and local decisions are of particular importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an implemented sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides a quick receipt of a practical schedule, and does not simply create another document for administrative control. If the system ignores getting stuck in locally profitable actions, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual decisions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [2].

From the perspective of production management, heuristic rules cannot be evaluated in isolation from other elements of the system. Even if the priority rules and local solutions are described in sufficient detail, their impact on the result depends on how they interact with shift calendars, work queues, material availability, equipment condition, and customer order priorities. An intelligent system must not only capture this interaction, but also show what consequences each management decision will have. That is why quickly obtaining a practical schedule becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it increases the blockage in locally profitable actions. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress, or worsen the fulfillment of deadlines [2].

5.4.2.2.3. Metaheuristics.

Within the topic of "metaheuristics", genetic algorithms, tabu search and swarm methods acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach lies in the fact that it provides a search for solutions in a large space of options, and does not simply create another document for administrative control. If the system ignores excessive complexity of the setup, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [1], [5].

From the perspective of production management, metaheuristics cannot be evaluated in isolation from other elements of the system. Even if genetic algorithms, tabu search, and swarm methods are described in sufficient detail, their impact on the result depends on how they interact with shift calendars, work queues, material availability, equipment condition, and customer order priorities. An intelligent system must not only capture this interaction, but also show what consequences each management decision will have. That is why the search for solutions in a large space of options becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it increases the excessive complexity of the setup. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress, or worsen the fulfillment of deadlines [1], [5].

5.4.2.2.4. Machine learning.

Within the scope of the topic of "machine learning", historical data on operations, downtime and quality acquires special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into a sequence of actions. For the planner, it is important to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides an increase in the accuracy of forecasts, and does not simply create another document for administrative control. If the system ignores learning on erroneous or biased data, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual decisions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [5].

From the perspective of production management, machine learning cannot be evaluated in isolation from other elements of the system. Even if historical data on operations, downtime and quality are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why increasing the accuracy of forecasts becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it does not strengthen learning on erroneous or biased data. In complex production, local optimization can create hidden losses in adjacent sections, increase work in progress or worsen the fulfillment of deadlines [5].

5.4.2.2.5. Simulation modeling.

Within the topic of "simulation modeling", the model of flows, queues and resources acquires special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides verification of scenarios without risk for the shop, and does not simply create another document for administrative control. If the system ignores the oversimplification of the system's behavior, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [4].

From the perspective of production management, simulation modeling cannot be evaluated in isolation from other elements of the system. Even if the model of flows, queues and resources is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why risk-free scenario testing for the shop floor becomes an important condition not only for operational efficiency, but also for confidence in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether it increases the oversimplification of the system's behavior. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [4].

5.4.2.2.6. Digital footprint of production.

Within the topic of “digital production footprint”, the actual events of order fulfillment are of particular importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. For the planner, it is important to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides an analysis of the causes of deviations and recurring losses, and does not simply create another document for administrative control. If the system ignores incomplete registration of operations, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [6].

From the perspective of production management, the digital footprint of production cannot be assessed in isolation from other elements of the system. Even if the actual events of order fulfillment are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the analysis of the causes of deviations and recurring losses becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it is not exacerbated by incomplete registration of operations. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [6].

5.4.2.2.7. Data quality.

Within the topic of “data quality”, directories, routes, calendars and balances acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into a sequence of actions that can be performed. For the planner, it is important to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides a stable basis for automatic planning, and does not simply create another document for administrative control. If the system ignores duplication and inconsistency of information, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [3].

From the point of view of production management, data quality cannot be assessed in isolation from other elements of the system. Even if directories, routes, calendars and balances are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why a stable basis for automatic planning becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether it increases duplication and inconsistency of information. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [3].

5.4.2.2.8. Multi-criteria optimization

Within the topic of “multi-criteria optimization”, deadlines, costs, loads, stocks and risks acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an implemented sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach lies in the fact that it provides the choice of a compromise plan, and does not simply create another document for administrative control. If the system ignores the dominance of one indicator over others, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [1], [4].

From the perspective of production management, multi-criteria optimization cannot be evaluated in isolation from other elements of the system. Even if the terms, costs, loads, inventories and risks are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the choice of a compromise plan becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it increases the dominance of one indicator over others. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [1], [4].

5.4.3. Intelligent dispatching, systems integration and digital production loop.

Dispatching is the level of production management at which the plan meets the actual reality of the shop floor. It is here that it becomes clear whether the initial assumptions were correct, whether materials are available, whether the equipment is working, whether the personnel have time to complete the task, and whether new priorities have arisen. If planning forms the intention of the enterprise, then dispatching ensures its implementation in specific conditions of time, place, and resource. In the traditional model, the dispatcher often acted as an intermediary between the planning department and the production areas, transferring tasks, monitoring their implementation, and resolving conflicts. Intelligent dispatching changes this role: it gives the dispatcher a digital picture of production and offers options for responding to deviations [6].

Operational management cannot be effective without the integration of information systems. The ERP system contains data on orders, purchases, finances and warehouse balances; the MES system displays the execution of operations in the shop; the APS system calculates schedules taking into account constraints; maintenance systems contain information on the condition of equipment; WMS and TMS support warehouse and transport logistics. If these systems are isolated, the dispatcher receives a fragmented picture and is forced to manually coordinate information. If they are integrated, a closed control loop arises in which the plan, fact, analysis and replanning are interconnected [3].

The digital twin of production is a promising form of such integration. It not only accumulates data, but also reproduces the logic of the functioning of the production system, allowing to simulate the consequences of decisions. For dispatching, this means the ability to check what will happen after transferring an operation, starting an additional shift, changing the priority of an order, or disabling a certain resource. In combination with cyber-physical systems, the digital twin turns into an active management tool, since real production objects constantly transmit data, and the digital model returns recommendations or commands [6].

5.4.3.3.1. Operational control of implementation.

Within the topic of "operational control of execution", the actual state of operations and orders acquires special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides rapid detection of deviations, and does not simply create another document for administrative control. If the system ignores late information from the shop, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [3], [6].

From the point of view of production management, operational control of execution cannot be assessed in isolation from other elements of the system. Even if the actual state of operations and orders is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why rapid detection of deviations becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it is exacerbated by late information from the shop. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [3], [6].

5.4.3.3.2. Reactive replanning.

Within the framework of the topic of “reactive replanning”, the change of the schedule after the event acquires special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the minimization of the consequences of failures, and does not simply create another document for administrative control. If the system ignores an excessive number of manual changes, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [1], [2].

From the perspective of production management, reactive replanning cannot be evaluated in isolation from other elements of the system. Even if the schedule change after an event is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, equipment technical condition, and customer order priorities. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why minimizing the consequences of failures becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it is exacerbated by excessive manual changes. In complex production, local optimization can create hidden losses in adjacent areas, increase work-in-progress, or worsen deadline compliance [1], [2].

5.4.3.3.3. Dispatching rules.

Within the topic of “dispatching rules”, priorities, time reserve and readjustment are of particular importance, since it is this element that determines the extent to which the production system is able to transform the management intention into a performed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the ordering of the work queue, and not simply creates another document for administrative control. If the system ignores the mechanical application of one rule, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [2].

From the perspective of production management, dispatching rules cannot be evaluated in isolation from other elements of the system. Even if priorities, time reserves and reconfiguration are described in sufficient detail, their impact on the result depends on how they interact with shift calendars, work queues, material availability, technical condition of equipment and customer order priorities. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why streamlining the work queue becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it does not reinforce the mechanical application of one rule. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [2].

5.4.3.3.4. ERP , MES and APS.

Within the topic of " ERP , MES and APS ", a single information loop acquires special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. For a planner, it is important to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the coordination of the plan, the fact and resources, and does not simply create another document for administrative control. If the system ignores the incompatibility of directories and processes, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not an agreed digital loop. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [3].

From the perspective of production management , ERP , MES , and APS cannot be evaluated in isolation from other system elements. Even if a single information loop is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, equipment status, and customer order priorities. An intelligent system must not only capture this interaction, but also show what consequences each management decision will have. That is why the coordination of the plan, facts, and resources becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it increases the incompatibility of directories and processes. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress, or worsen the fulfillment of deadlines [3].

5.4.3.3.5. Industrial Internet of Things.

Within the scope of the “industrial Internet of Things” topic, sensors, controllers, and production events are of particular importance, since it is this element that determines the extent to which the production system is able to transform a management intention into a sequence of actions that can be performed. For a planner, it is important to see not only a formal calendar, but also cause-and-effect relationships between the order, materials, resources, technological routes, and constraints. The practical value of such an approach is that it provides real-time data, and not just creates another document for administrative control. If the system ignores the excessive flow of unverified information, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool is the experience of individual employees, rather than a coordinated digital circuit. Therefore, an intelligent model should combine formal rules, actual data, and expert understanding of production logic [6].

From the perspective of production management, the Industrial Internet of Things cannot be evaluated in isolation from other elements of the system. Even if sensors, controllers, and production events are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, equipment condition, and customer order priorities. An intelligent system must not only capture this interaction, but also show what consequences each management decision will have. That is why obtaining data in real time becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it increases the excess flow of unverified information. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress, or worsen the fulfillment of deadlines [6].

5.4.3.3.6. Digital twin.

Within the scope of the "digital twin" topic, a virtual model of a workshop or enterprise acquires special importance, since it is this element that determines the extent to which a production system is able to transform a management intention into an executed sequence of actions. It is important for a planner to see not only a formal calendar, but also cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach lies in the fact that it provides verification of scenarios before their execution, and does not simply create another document for administrative control. If the system ignores the inaccuracy of the real process model, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [6].

From the perspective of production management, a digital twin cannot be evaluated in isolation from other elements of the system. Even if the virtual model of a workshop or enterprise is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment, and customer order priorities. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why checking scenarios before their execution becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether it increases the inaccuracy of the real process model. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress, or worsen the fulfillment of deadlines [6].

5.4.3.3.7. Managing bottlenecks in dispatching.

Within the topic of "bottleneck management in dispatching", the limiting resource in the current shift acquires special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach lies in the fact that it ensures the subordination of the flow to the main constraint, and does not simply create another document for administrative control. If the system ignores local optimization of neighboring sections, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [4].

From the perspective of production management, bottleneck management in dispatching cannot be assessed in isolation from other elements of the system. Even if the limiting resource in the current shift is described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the subordination of the flow to the main constraint becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether local optimization of neighboring sections enhances it. In complex production, local optimization can create hidden losses in neighboring sections, increase work in progress or worsen the fulfillment of deadlines [4].

5.4.3.3.8. Communication between departments.

Within the topic of "communication between departments", planners, foremen, purchasing, warehouse and sales acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an implemented sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides a single understanding of priorities, and does not simply create another document for administrative control. If the system ignores the conflict of goals and informal agreements, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than an agreed digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [3], [4].

From the perspective of production management, communication between departments cannot be assessed in isolation from other elements of the system. Even if planners, foremen, purchasing, warehouse and sales are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why a single understanding of priorities becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it does not increase the conflict of goals and informal agreements. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [3], [4].

5.4.4. Implementation, effectiveness, risks and prospects for the development of intelligent planning.

The implementation of intelligent planning and dispatching is a complex organizational and technological project that cannot be reduced to the purchase of software. Its success depends on the willingness of the enterprise to change processes, improve data quality, train personnel, review the distribution of responsibilities and measure the result according to understandable indicators. Often, enterprises start with the desire to get a quick effect in the form of reducing delays or increasing equipment utilization, but very quickly they are faced with deeper questions: who is responsible for the accuracy of routes, how the fact of the operation is recorded, which orders have priority, when manual intervention is allowed and how to assess the quality of the plan. It is these questions that determine the practical value of a digital system [3].

The effectiveness of intelligent planning should be measured not by a single indicator, but by a system of interrelated criteria. An enterprise can achieve high equipment utilization, but at the same time increase the order processing time due to the accumulation of work in progress. It can reduce inventories, but increase the risk of downtime due to a lack of materials. It can minimize the number of re-adjustments, but worsen the fulfillment of urgent orders. Therefore, the assessment should take into account the balance between throughput, cycle time, inventory, reliability, cost and flexibility. This approach corresponds to the logic of factory physics, where the relationships between variability, flow and resource constraints play a key role [4].

The prospects for the development of intelligent planning are associated with the transition from the automation of individual functions to the creation of self-learning production ecosystems. Such ecosystems will combine demand forecasting, supply management, production planning, dispatching, quality control, maintenance, energy management and logistics. They will not only react to events, but also form preventive solutions. However, the future does not mean the complete elimination of humans from management; on the contrary, the role of specialists who are able to formulate goals, assess risks, explain algorithm solutions and responsibly apply digital tools will increase [5], [7].

5.4.4.4.1. Implementation stages.

Within the topic of "implementation stages", diagnostics, pilot, scaling and stabilization acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an implemented sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures a reduction in project risk, and does not simply create another document for administrative control. If the system ignores the attempt to automate the entire enterprise at the same time, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [3].

From the perspective of production management, the implementation stages cannot be evaluated in isolation from other elements of the system. Even if diagnostics, pilot, scaling and stabilization are described in sufficient detail, their impact on the result depends on how they interact with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why reducing project risk becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether it is not exacerbated by the attempt to automate the entire enterprise at the same time. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [3].

5.4.4.4.2. Organizational readiness.

Within the framework of the topic of "organizational readiness", processes, roles, responsibilities and data discipline acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into a performed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the transformation of technology into a working tool, and not simply creates another document for administrative control. If the system ignores the formal resistance of the staff, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [3], [5].

From the perspective of production management, organizational readiness cannot be assessed in isolation from other elements of the system. Even if processes, roles, responsibilities, and data discipline are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, equipment condition, and customer order priorities. An intelligent system must not only capture this interaction, but also show what consequences each management decision will have. That is why the transformation of technology into a working tool becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is when management tries to achieve local improvement without checking whether it increases formal resistance from personnel. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress, or worsen deadline compliance [3], [5].

5.4.4.4.3. Economic efficiency.

Within the scope of the topic of “economic efficiency”, costs, deadlines, inventories, downtime and customer service acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into a sequence of actions that can be performed. For a planner, it is important to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides a justification for investments in digitalization, and does not simply create another document for administrative control. If the system ignores the assessment of only direct costs, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than an agreed digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [4], [7].

From the perspective of production management, economic efficiency cannot be assessed in isolation from other elements of the system. Even if costs, deadlines, inventories, downtime and customer service are described in sufficient detail, their impact on the result depends on how they interact with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the justification of investments in digitalization becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it does not increase the assessment of only direct costs. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [4], [7].

5.4.4.4.4. Human factor.

Within the framework of the topic "human factor", planners, dispatchers, foremen and operators acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into a performed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides a combination of experience and algorithmic support, and does not simply create another document for administrative control. If the system ignores distrust of the system's recommendations, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [5].

From the perspective of production management, the human factor cannot be assessed in isolation from other elements of the system. Even if planners, dispatchers, foremen and operators are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the combination of experience and algorithmic support becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it does not increase distrust in the system's recommendations. In complex production, local optimization can create hidden losses in adjacent areas, increase unfinished production or worsen the fulfillment of deadlines [5].

5.4.4.4.5. Data and model risks.

Within the topic of “data and model risks”, incomplete data, biased forecasts and outdated rules acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the reliability of the digital system, and not simply creates another document for administrative control. If the system ignores the uncritical acceptance of the results of the algorithm, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [5], [6].

From the perspective of production management, data and model risks cannot be assessed in isolation from other elements of the system. Even if incomplete data, biased forecasts and outdated rules are described in sufficient detail, their impact on the result depends on how they interact with shift calendars, work queues, material availability, technical condition of equipment and customer order priorities. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why maintaining the reliability of the digital system becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it does not increase uncritical acceptance of the algorithm's results. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [5], [6].

5.4.4.4.6. Cybersecurity and continuity.

Within the framework of the topic of “cybersecurity and continuity”, integrated production systems and network risks acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. For the planner, it is important to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it provides protection of the operational circuit, and not simply creates another document for administrative control. If the system ignores the loss of access to critical data, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [6].

From the perspective of production management, cybersecurity and continuity cannot be assessed in isolation from other elements of the system. Even if integrated production systems and network risks are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why protecting the operational loop becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is a situation when management tries to achieve local improvement without checking whether the loss of access to critical data does not exacerbate it. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [6].

5.4.4.4.7. Sustainable production.

Within the framework of the topic of "sustainable production", energy, waste, environmental criteria and carbon footprint acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into a performed sequence of actions. It is important for the planner to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach is that it ensures the coordination of efficiency with responsibility, and does not simply create another document for administrative control. If the system ignores the ignoring of external constraints, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, and not a coordinated digital circuit. Therefore, the intelligent model should combine formal rules, actual data and expert understanding of production logic [7].

From the perspective of production management, sustainable production cannot be assessed in isolation from other elements of the system. Even if energy, waste, environmental criteria and carbon footprint are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system should not only record this interaction, but also show what consequences each management decision will have. That is why the coordination of efficiency with responsibility becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it does not increase the ignoring of external constraints. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [7].

5.4.4.4.8. The future of autonomous systems.

Within the topic of “the future of autonomous systems”, self-learning algorithms and the joint intelligence of man and machine acquire special importance, since it is this element that determines the extent to which the production system is able to transform the management intention into an executed sequence of actions. For a planner, it is important to see not only the formal calendar, but also the cause-and-effect relationships between the order, materials, resources, technological routes and constraints. The practical value of such an approach lies in the fact that it ensures the adaptation of the enterprise to uncertainty, and does not simply create another document for administrative control. If the system ignores the transfer of responsibility to technology, the plan quickly loses its realism, and the dispatcher is forced to correct the situation using manual solutions. As a result, the enterprise returns to reactive management, where the main tool becomes the experience of individual employees, rather than a coordinated digital circuit. Therefore, an intelligent model should combine formal rules, actual data and expert understanding of production logic [5], [6], [7].

From the perspective of production management, the future of autonomous systems cannot be assessed in isolation from other elements of the system. Even if self-learning algorithms and joint human-machine intelligence are described in sufficient detail, its impact on the result depends on how it interacts with shift calendars, work queues, material availability, technical condition of equipment and priorities of customer orders. An intelligent system must not only record this interaction, but also show what consequences each management decision will have. That is why the adaptation of the enterprise to uncertainty becomes an important condition not only for operational efficiency, but also for trust in the plan. A typical mistake is the situation when management tries to achieve local improvement without checking whether it increases the transfer of responsibility to technology. In complex production, local optimization can create hidden losses in adjacent areas, increase work in progress or worsen the fulfillment of deadlines [5], [6], [7].

General provisions to the expanded edition. The issue of the ratio of centralized and decentralized control requires special attention. In small production systems, one planning center can relatively quickly coordinate all resources, but with an increase in the number of operations, sections and route options, centralized manual control loses speed. Intelligent systems make it possible to leave strategic decisions at the management level, and transfer part of the operational coordination to algorithms or local rules. For example, the central system can determine general priorities and permissible limits, and the shop level can specify the actual sequence of work taking into account the current situation. Such a model is especially useful for discrete production, where technological routes may have alternatives, and the delay of one operation quickly affects the subsequent flow [2], [6].

No less important is the question of the planning horizon. The long-term horizon allows you to estimate the need for capacity, procurement and personnel, but it inevitably contains more uncertainty. The short-term horizon is more accurate, but can lead to decisions that are profitable today, but create problems next week or month. Therefore, an intelligent system must work with several horizons simultaneously: strategic, tactical, operational and dispatching. Each horizon uses different levels of detail, different criteria and different responsibilities. Coordination of these horizons is one of the main conditions for mature production management [3].

In today’s enterprise, planning increasingly extends beyond a single shop or plant. It is linked to suppliers, service partners, transportation companies, customer schedules, and even energy markets. If a material has a long lead time or a critical component depends on an external contractor, the internal production schedule cannot be optimized in isolation. That is why intelligent planning must consider the supply chain as an extension of the production system. In the future, competitiveness will be determined not only by the efficiency of an individual enterprise, but also by the ability of the entire network of partners to coordinate plans, risks, and capacities [7].

The problem of trust in algorithms is especially acute in situations where the system's recommendation contradicts the usual experience of the personnel. For example, the system may suggest not to run the order closest in time if this will lead to a large loss of time for reconfiguration and disruption of several other orders. For a person, such a decision may seem illogical without an explanation of the reasons. Therefore, the interface of intelligent planning should show not only the final schedule, but also the constraints that influenced the choice: availability of materials, bottlenecks, time reserve, cost of reconfiguration, forecast risk and consequences of alternatives. Explainability becomes a condition for the acceptance of the system by users [5].

Conclusions. To summarize, intelligent production planning and dispatching is the answer to the growing complexity of industrial systems. It is not limited to automatic scheduling, but encompasses forecasting, data analysis, constraint detection, scenario evaluation, operational decision support, and continuous improvement of the production model. Its essence is to transform production from a reactive system that constantly adapts to problems after they arise, to a proactive system that can predict deviations and prepare solutions in advance.

The most important condition for the successful application of intelligent systems is the quality of data and the maturity of processes. Without reliable routes, realistic time standards, current balances, the discipline of fact registration and agreed priority rules, even the most modern algorithms will not provide the expected effect. Therefore, the digitalization of production planning should begin not with the choice of a software platform, but with the analysis of the real production process, the identification of information gaps and the formation of a single management logic.

Artificial intelligence, digital twins, cyber-physical systems and optimization techniques offer significant potential for increasing productivity, shortening production cycles, reducing downtime, improving customer service and reducing operational risks. However, they do not eliminate the role of humans. On the contrary, an effective model of the future involves the joint intelligence of humans and algorithms, where the system takes on the calculations, monitoring and forecasting, and humans set goals, assess non-standard situations, take responsibility and ensure the connection between production decisions and the company's strategy.

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5.5. Архітектура як інструмент формування просторів для соціально-психологічного відновлення військових

В роботі проаналізовано закордонний досвід проектування та експлуатації реабілітаційних центрів. Інформаційну базу склали наукові публікації у фахових виданнях, присвячених формуванню архітектури таких центрів та порівняльний аналіз архітектурних рішень сучасних реабілітаційних центрів.. Визначено основні чинники, що впливають на формування архітектури реабілітаційних центрів. Запропонована модель нового реабілітаційного центру, що враховує сучасні підходи до формування його архітектури. Ключові слова: посттравматичний стресовий розлад, системно-структурний аналіз, релаксація, ментальні розлади, архітектурне середовище, адаптивна архітектура , терапевтична архітектура.

Вступ. Збройна агресія росії проти України, що триває з 2014 року та набула безпрецедентних масштабів після повномасштабного вторгнення 2022-го, залишає глибокий відбиток на фізичному та ментальному стані нації, насамперед – військовослужбовців. У контексті тривалого конфлікту питання відновлення здоров'я