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DIGITAL TRANSFORMATION OF LOGISTICS AND PRODUCTION PROCESSES IN SHORT-RUN PRINTING UNDER THE EDGE COMPUTING–BASED BUSINESS MODEL TRANSITION

The transformation of the modern printing industry within the framework of the Industry 4.0 concept has driven a shift from static models of mass production to dynamic systems of on-demand manufacturing. The operational specificity of such networks is characterized by the inflow of a large number of small-scale orders with variable technical parameters, generating a continuous stream of input data [1, p. 1055]. Under these conditions, the efficiency of the business model directly depends on the speed of information processing and the responsiveness of managerial decision-making regarding resource allocation. Traditional planning methods, based on stable production schedules, are losing relevance due to high demand volatility and the necessity of accounting for the real-time condition of equipment. The centralization of computational processes in cloud-based storage environments during the analysis of large-scale data sets is often accompanied by signal transmission latency, which limits the ability to respond instantaneously to changes in the production environment [2, p. 10].

Such a transformation of the business model imposes stringent requirements on decision-making speed, as the time interval between the moment a request is received and the commencement of its technological implementation is reduced to a minimum. Within the framework of the digitalization of logistics and production processes, the system's ability to perform instantaneous cost calculation and determine the execution sequence of orders in a dynamic mode becomes particularly critical. Traditional static price lists and fixed equipment loading schedules prove inadequate for responding to sudden fluctuations in demand or the specific technical requirements of individual layouts. Consequently, there arises a need to implement dynamic pricing mechanisms, where price functions not merely as an economic indicator but as a tool for operational regulation of the incoming workflow through value-based levers. This process necessitates simultaneous processing of substantial data sets regarding the current state of production lines, the availability of specific substrate types in stock, and the anticipated completion times of preceding operations. Under these conditions, the prioritization of order execution ceases to be linear and transforms into a multifactor optimization model, which must account not only for the urgency indicated by the client but also for the resource intensity of the order and its impact on the overall stability of the network's technological cycle. The requirement for instantaneous synchronization of these parameters imposes a high load on the information infrastructure, as delays in data processing directly correlate with potential revenue loss and reduced customer loyalty. Therefore, the transition to a business model oriented toward individualized requests effectively nullifies the feasibility of centralized long-term planning, replacing it with algorithmic real-time management. This creates objective conditions for the exploration of new architectural solutions in data processing capable of providing the necessary computational speed directly at the points of request origination, which is critically important for maintaining the competitiveness of distributed printing networks in the digital economic space. Accordingly, the speed of managerial response becomes the primary determining factor defining the viability of the modern service-oriented print-on-demand model.

The further development of the digital transformation concept in short-run printing necessitates a detailed analysis of the architecture of information flows that ensure the operation of distributed production networks. As noted, the traditional use of cloud computing for processing large-scale data sets faces a number of objective limitations imposed by the physical parameters of signal transmission and the bandwidth of communication channels [3, p. 208]. In the context of the print-on-demand model, where the time interval between layout validation and the activation of the printing module is measured in seconds, any delay in interaction with a remote server leads to the desynchronization of logistics chains (Fig. 1).

Centralized processing of incoming requests, rasterization technical parameters, and equipment logs on remote facilities creates the risk of computational bottlenecks, which under conditions of high request intensity translates into direct financial losses. The economic feasibility of operating short-run printing points directly correlates with minimizing equipment downtime and the speed of task preparation for execution. High dependence on the stability and speed of external network connections renders business processes vulnerable to traffic fluctuations, thereby negating the advantages of digitalized management at the local level [4, p. 208]. Consequently, there is an emerging need to implement flexible data processing tools capable of operating autonomously within a specific production node. The transition to edge computing enables the relocation of analytical workloads directly to the point of data generation, that is, to the level of printing machine controllers and local control terminals.

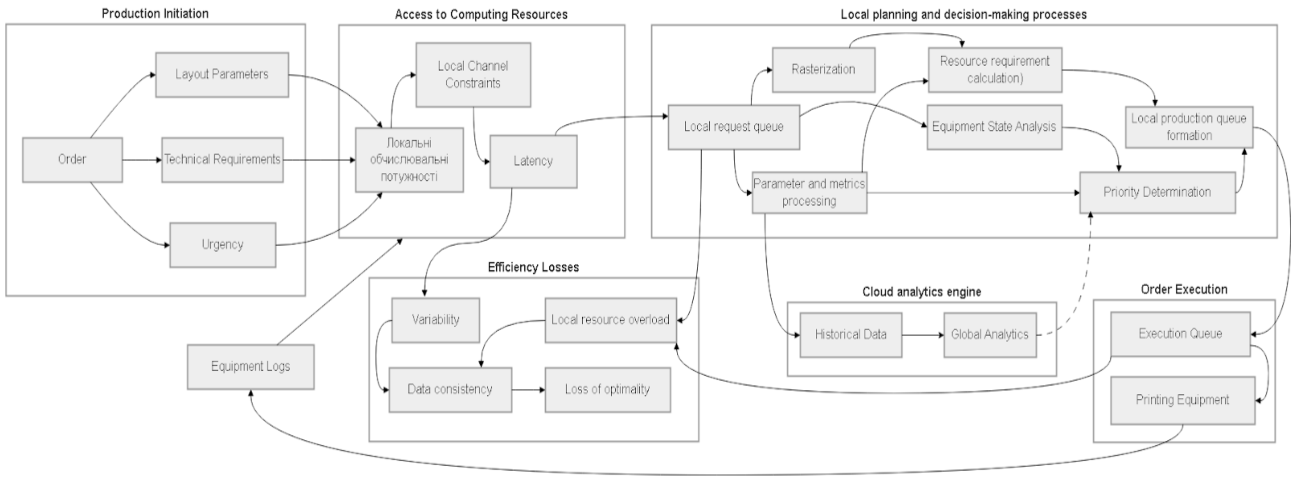

Figure 1 – Centralized business model of logistics and production processes in short-run printing

This allows complex calculations of resource intensity and order prioritization to be performed without the necessity of constant communication with a cloud server for each individual operation. Local processing of technical metrics enables the system to instantly adapt printing parameters to the actual state of equipment and substrate availability, ensuring continuity of the technological cycle even under unstable connections with the central database (Fig. 2).

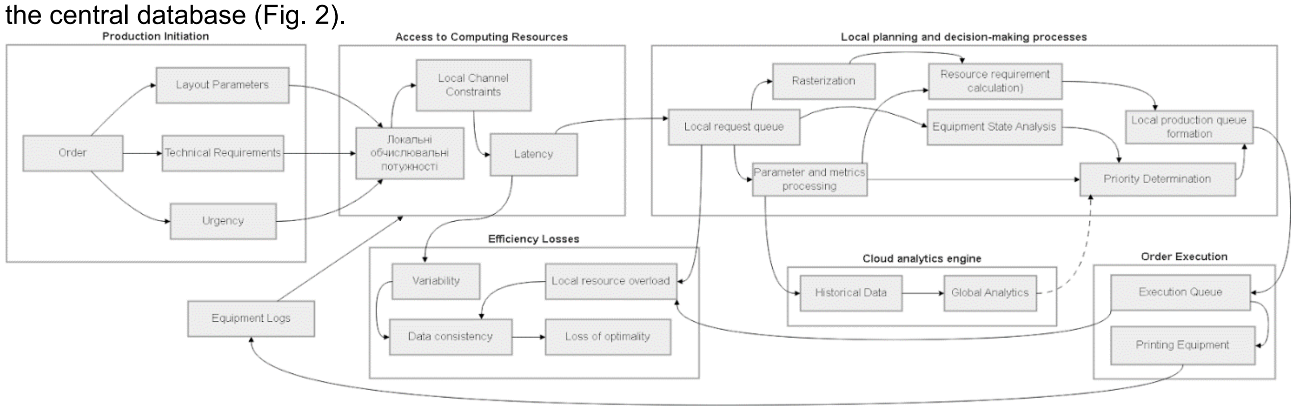

Figure 2 – Distributed business model of logistics and production processes in short-run printing

Thus, optimizing the business model through the decentralization of computational resources becomes a necessary condition for maintaining the high operational speed characteristic of modern digital networks. The formation of such architecture enables the conversion of large-scale data sets into concrete managerial commands with minimal temporal lag, which is a fundamental requirement for implementing dynamic pricing algorithms and automated queue planning. The deployment of edge infrastructure transforms the logistics and production environment into a network of intelligent nodes capable of autonomous real-time process optimization, thereby minimizing the impact of network latency on the overall economic efficiency of the enterprise. The distributed data processing model becomes the foundation for building a resilient digital ecosystem, where computational speed aligns with the dynamics of market demand. Moreover, such a distributed business model of logistics and production processes in short-run printing is crucial for implementing predictive maintenance [5, p. 444], enabling real-time monitoring of equipment conditions, anticipatory adjustment of production schedules, and proactive mitigation of potential operational disruptions. This integration ensures not only continuous workflow efficiency but also prolongs equipment lifespan and enhances the overall reliability and responsiveness of the printing network.

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