Research article

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Implementation of Digital Tools in the Operational Management of Material Procurement at Machinery Enterprises

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Abstract

Operational management of material resources has become a major concern for machinery enterprises. Growing interest in this issue rests on multiple reasons, primarily increasing the costs of material resources, their significant effect on efficiency and competitiveness, the complexity of cutting-edge processes involved in resource management, and economic and political turbulence worldwide. In an era when new business processes are emerging, and the older ones are being improved and accelerated, digitalisation is becoming one of the major drivers for innovation in enterprise management. Readjustments also occur in the infrastructure and fabric of departments and staff, alongside the methods of motivation and performance assessment. This paper presents scientific findings from domestic and international research to consider the most urgent challenges that the machinery industry faces in its ongoing digitalisation. Specific attention is paid to the external and internal environment of machinery enterprises, their ability to adapt to dynamic fluctuations in demand, and unpredictable changes in supply and consumption. Further, the authors develop a range of methods and tools aimed at improving efficiency of calculation, and integrating a whole-scale approach to provide an enterprise with materials of the required quantity and quality in a timely manner, with the lowest costs and optimal reserves.

Keywords: material supply, dynamic multi-type production, digitalisation, engineering

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Применение Цифровых Инструментов в Оперативном Управлении Поставкой Материалов на Машиностроительных Предприятиях

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Аннотация

Оперативному управлению обеспечением материальными ресурсами (ОУОМР) предприятий, традиционно, а в последнее время в возрастающей степени уделяется большое внимание. Объясняется это их возрастающей ролью в бизнесе, ростом затрат на них, влиянием их на эффективность и конкурентоспособность предприятий, усложнением ОУОМР в связи с ускорением научно-технического прогресса, ростом динамики внешней и внутренней среды предприятий, экономической и политической нестабильностью в мире. Цифровизация становится одним из приоритетных направлений инновационного развития управления предприятием, появляются новые и трансформируются старые бизнес-процессы, которые оптимизируются, насыщаются информационными потоками и ускоряются. Модернизируется инфраструктура предприятий, функции подразделений и работников, методы оценки и мотивации их деятельности. В статье на основе отечественных и зарубежных публикаций, собственных разработок авторов рассмотрены проблемные вопросы цифровизации ОУОМР для разнотипного машиностроительного производства при динамике внешней и внутренней среды предприятия, в первую очередь к динамичному изменению спроса на продукцию предприятий, непрогнозируемым изменениям поставки и потребления материалов. Предложены методы и инструменты, направленные на повышение оптимальности, оперативности, детализации расчетов, комплексного подхода с целью своевременного обеспечения предприятия материалами необходимого количества и качества в требуемые сроки с наименьшими затратами и оптимальными запасами.

Ключевые слова: поставка материалов, динамичное разнотипное производство, цифровизация, машиностроение

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1. Introduction

In recent years, an enterprise's ability to compete and stay afloat has begun to rely heavily on the efficiency of its procurement activities and their management. Reduction of purchasing costs is one of the most evident and long-standing ways to boost profitability, ensure high quality, and stimulate innovation. A variety of material assets and inventory items at a large machinery enterprise amount to tens and hundreds of thousands of units. About 20–60% of a prime cost is taken by semi–finished and finished componentry (hereinafter, materials). The development of an effective system for procurement management will reduce these costs and subsequently create a prerequisite for the sustainability of an enterprise. The market economy depends on expansion and rapid changes in product range demanded by consumers, harsh timing for introduction of newly designed items into production, cuts in production cycle, and growing competition. All these trends create grounds for enterprises to improve their material and technical supplies, and strengthen quality control in procurement logistics.

Logistics has become a major sufferer in the conditions of economic and political turbulence, pandemics, and military operations. Among other things, Russian logistics is vastly affected by a weak ruble, traditional trade and industrial ties between countries disrupted by sanctions and embargoes, sky, ports, and borders closed by "unfriendly countries", transport routes either getting closed or changed, decrease in volumes of cargo transportation and passenger traffic, impeded labour migration, etc. The major outcome is that the population is losing its purchasing power. Trade flows are getting weaker, logistics costs and commodity prices are skyrocketing, businesses are suffering, and suppliers are incapable of forecasting their prospects. As a result, many of them, especially small and medium enterprises, are either closing or reducing production. Consequently, supply chains were destabilised for almost all enterprises because the borders were closed. Serious disruptions in supply and logistics occurred; thus, many enterprises were forced to quickly look for new suppliers and diversify production and supply chains. Therefore, logistics and staff are becoming two major concerns for machinery enterprises.

The global background is experiencing significant changes as well, with the World Trade Organization (WTO) losing its leadership due to economic, political, and military pressure from a number of countries. As a result, considering economic reasons exclusively is no longer a viable strategy for designing logistics projects. Due consideration is currently supposed to refer to political and even military outcomes.

Digitalisation is becoming one of the priorities in the innovation of enterprise management, including the operational management of material resources. In this regard, new business processes are emerging, and old ones are being transformed, updated, and accelerated. Readjustments also occur in the infrastructure and fabric of departments and staff, alongside the methods of motivation and performance assessment. Most importantly, digitalisation should be aimed at the following results: acceleration of business processes, improvement of decision-making, ability to adjust to changes in supply and demand, development of a personalised approach to consumers, transparency of data throughout the supply chain, and high efficiency of business processes. The entire supply chain (supply-finished product-consumer) calls for integrated digitalisation, which is only possible when a common information and communication space is ensured. Digital production is associated not only with the introduction of new technologies but also with a profound transformation of development strategy, corporate structure, management, and interaction with contractors. In other words, whole-scale rewiring requires new methods for the development of enterprise architecture and management models (Dubolazov, 2021).

This study aims to identify methods of operational management of materials supply that focus on increasing the efficiency of decision making at machinery enterprises, with all due consideration of planning and production specifics. The study strives to define instruments and digital tools for boosting the transparency of supply, cutting costs, and improving processes associated with resource planning, etc.

2. Literature review

Wide discussion of digital tools and their implementation in economics and production started in 1995, when American computer scientist Nicholas Negroponte came up with the term “digitalisation” or “digital economy” (Negroponte, 2000). His ideas sparked widespread and whole-scale use of data, information, and digital resources in the industry. In 2016, K. Schwab introduced the notion of Industry 4.0 (Schwab, 2016), aimed at improving the competitiveness of manufacturing enterprises. At this point, traditional production processes have begun to change, with a new architecture of industrial systems being built, and a digital approach affecting all stages of the product life cycle.

Supply chain management took the leading position among the areas that actively implemented digital tools. Therefore, it came as no surprise that the concept of digital logistics developed rapidly. However, back then, multiple definitions of this newly-coined term concerned the issues of digitalisation in transport logistics and other functional industries. (Moldabekova et al., 2021; Barykin et al., 2021; Negreeva, 2020). Sergeev, Lukinsky, and Sherbakov are Russian researchers who considered classical models of calendar planning in material resources on the basis of average daily demand (Sergeev, 2019; Lukinsky, 2019; Shcherbakov, 2020). In their works, Sokolitsyn and Dubolazov (1980) assessed the features of the operational management of machinery enterprises, emphasising the importance of integrated planning. Konovalova (2019) examined the methodology of the operational management of digital production in machinery enterprises from a slightly different perspective. She focused mostly on the influence of various factors on the production complex and assessed the effects of digitalisation on the accuracy of production tasks and improvement of inventory potential. It is worth mentioning that her research “Provision of material resources at industrial enterprises” from 2019 is still highly relevant.

Figure 1 presents the range of scientific papers that have largely shaped the grounds for this research (collected from the Scopus database, 2000 to 2022). As shown in the figure, the topic of supply management for material resources has become increasingly relevant since 2019. This trend is primarily associated with in-depth research and the implementation of digital tools in enterprise management.

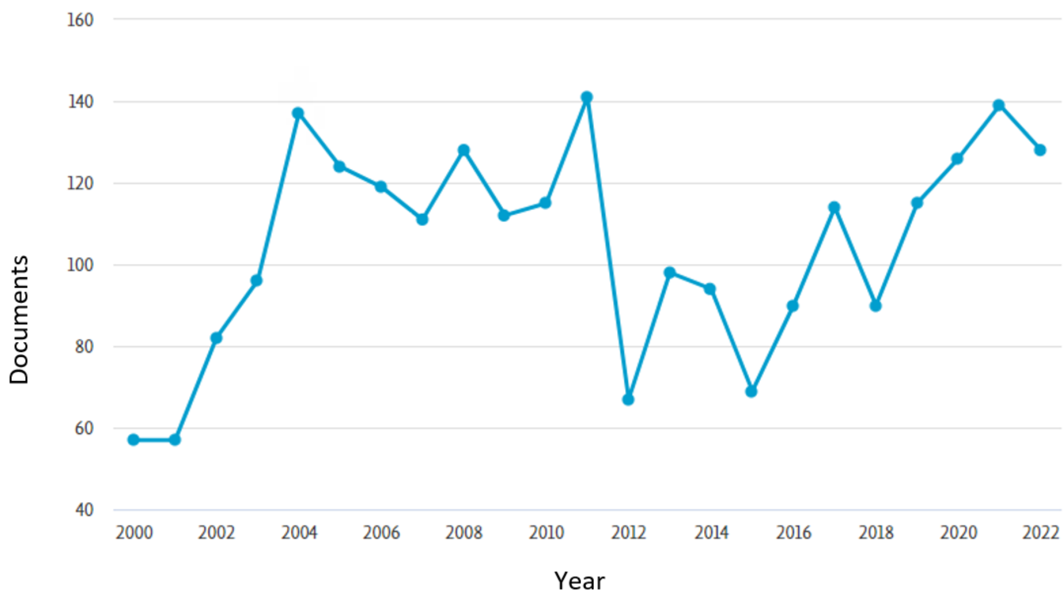

Figure 1. Collection of Scopus articles examined for this study. Search key term: “supply management industrial enterprises”

Many of the studies mentioned above have considered various models of material resource management used for a certain type of production. However, they seem to be of little use for different types of machinery enterprises, as they do not take into account the increasing dynamics of production and the constantly updated range of products that are being manufactured. Neglecting these factors impedes accurate planning of materials in demand, and inevitably leads to disruptions in supply, materials shortage, low-quality or costly materials being supplied, order declines, higher working capital, etc.

3. Materials and methods

Methodologically, this study rests on modern theories and guidelines of domestic and international scientists. The information bank for this study includes legislative and regulatory acts of the Russian Federation, resolutions of the Government of the Russian Federation, data from the Federal State Statistics Service, research materials, analytical reviews on the development of machinery, material resources at industrial enterprises, internet resources, etc. Fundamental theoretical and empirical methods were implemented in the research process. These primarily include observation, system analysis, synthesis, complex analysis and grouping, and economic and mathematical methods.

Efficiency and quality of operational management, especially regulation, are largely determined by the timely recorded deviations from a preplanned course of production, and accurate collecting, transmitting, and processing of operation-related data. Automated control systems that are now applied to a large extent are restricted to maintaining daily operational records and shift planning. Clearly, these systems improve the efficiency of operational management. However, they lead to a time lag in regulating production in terms of emerging deviations. Hence, it is necessary to develop an automated real-time control system, which is currently a real ambition due to the development of the internet of things (IoT) and other digitalisation means (Dubolazov, 2021).

Further, there is a whole range of challenges that impede effective demand planning and make it rather unpredictable, including ruble fluctuations, difficulties in international trade relations, particularly sanctions, import-export embargoes, multiple closed borders, restricted bank operations for Russia, etc. Many manufacturers and distributors note that the difference between planned and actual production volumes amounts to 10%, often 20%, or even more (Titov et al., 2017). As pointed out by manufacturers, problems associated with materials provision include excessive stocks, supply disruptions, high logistics costs, low quality of materials and logistics services, inadequate batches, and high prices of purchased materials (Dubolazov, 2017).

Therefore, these issues create an urgent task that all enterprises need to solve as quickly as possible. They must adapt to changing conditions in supply chains, including dynamic, and sometimes unexpected, changes in demand and materials supply. On the one hand, it is necessary to widen the planning time frame to establish delivery dates in advance following the main production roadmap. On the other hand, it is reasonable to shorten intervals of operational supply planning and adjust them to changes in demand for supplies and shifting schedules. This would be made possible through efficient readjustments in operational sales plans, production plans, and possibly even supply policies. Among other positive outcomes, enterprises may expect to improve planning flexibility, strengthen the reliability of supplies, and cut the costs of materials due to their shortage or excessive stocks. However, once an operational change in demand takes place, it would entail contract changes, since the previous frame is not likely to be profitable. The key solution to this issue is to find the best possible planning time frame.

4. Results

Stricter requirements for production intensity and quality rest on the number of developments, such as Industry 4.0 and Procurement 4.0, cuts in time for the introduction of products to the market, and transition to partnerships between sellers and buyers. In recent years, procurement activities around the world have largely focused on transparency and flexibility of supplies (their volume, product range, timing, transportation mode, new logistics routes, and possibility to withdraw an order). In other words, supply chain stakeholders can introduce timely adjustments to schedules when changes arise (Dybskaya, 2012).

Digitalisation 4.0 poses a set of the following changes for industrial enterprises (Kraus et al., 2021; Nyagadza et al., 2022):

- Digitalisation of products (including customisation) and services leads to an increase in qualitative and quantitative characteristics of products and services provided;

- Building and using digital business models and platforms to organise communication between counterparties;

- Ability to switch to integrated forecasting and production planning via data exchange, such as WMI;

- Digitalisation and integration of vertical and horizontal supply chains: As a result, internal and external business processes are rearranged, since a stakeholder is integrated into a single information system in real time (suppliers, consumers, intermediaries, etc.);

- Employee training in digital skills to ensure the internal transformation of an enterprise. Outstaffing seems to be one of the promising means for attracting highly qualified specialists from the outside.

Following the development of Procurement 4.0, it became easier for stakeholders to enjoy better transparency of supplies and obtain win-win contracts with suppliers. New technologies enable enterprises to manage costs in real mode, quickly negotiate via smart contracts, select preferred suppliers, automatically determine demand for material resources, eliminate duplicate orders and transactions, and monitor risks on site. Another benefit is that supplier management will allow the purchasing department to focus on ways to optimise procurement. Loss of leadership is an inevitable outcome for those companies who neglect the importance of digitalisation, Industry 4.0, Procurement 4.0, digital technologies, and the entire call for rearranging business processes and interaction with counterparties.

Notably, traditional models of calendar planning for material resources are based on average daily demand. However, the demand for materials tends to vary throughout a month, a week, or even a day. Therefore, when a fixed volume or frequency of supplies takes place, enterprises run the risk of excessive stocking. Further, these models were designed for a time when operational deviations of actual data from the preplanned were not taken into account. Nonetheless, modern machinery enterprises need the concept of an operational management system that would imply single methods and algorithms to perform—operational planning, accounting, control, assessment, and regulation of material resources. Such a concept should consider dynamics and combine single-unit and mass production (Figure 2).

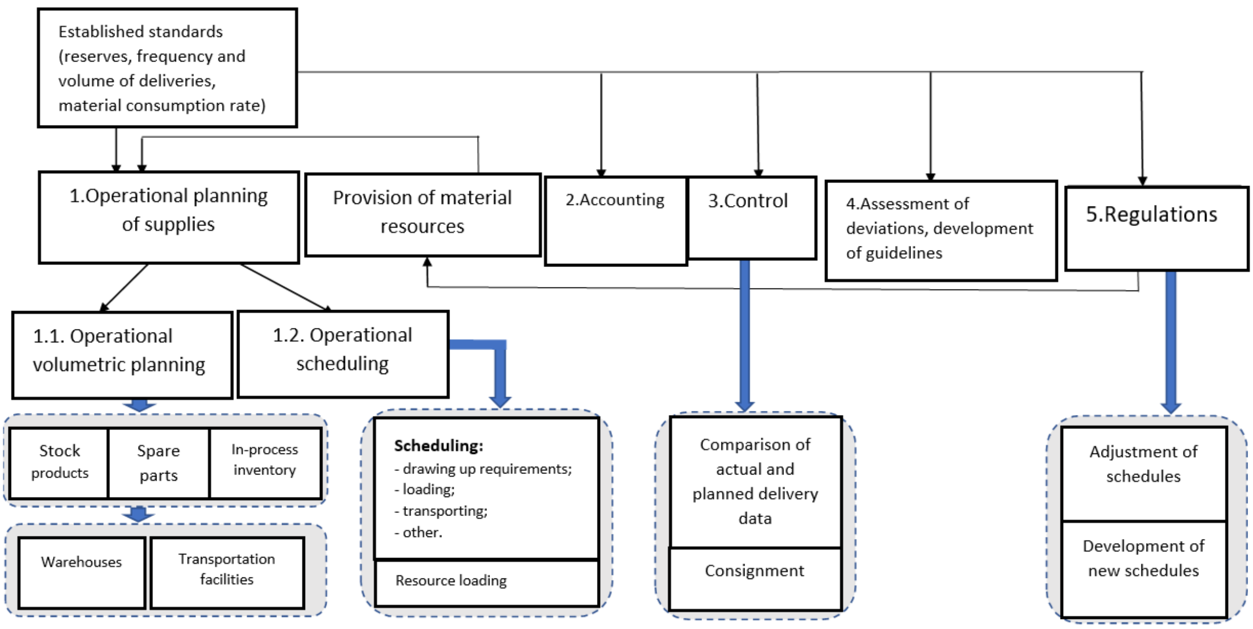

Figure 2. Operational management of procurement

In practice, deviations of actual indicators from the preplanned ones are potentially possible for various reasons, including changes in intensity of consumption, delivery of materials by a bigger or smaller batch, errors in data on the amount of stocking, materials in transit, etc. Most likely, various combinations of these reasons would occur. An important factor to pay attention to is that in mechanical engineering, different types of production prevail, and the output may differ by working days (weeks). The methodology developed in this study considers this factor and makes it possible to achieve more accurate supply planning, identify emerging deviations in time, and regulate further deliveries. The scientific novelty of this methodology is in its systematic approach, which accounts for the specifics of managing the provision of material resources at a machinery enterprise. This new approach is characterised by efficient plan adjustments to ensure timely supplies.

Figure 3 demonstrates this methodology by showing a proposed schedule for materials provision. Each stock item is controlled by three parameters. The first indicates the daily need for material resources. The second tracks daily demand on an accrual basis from the beginning of the month. The third shows the delivery schedules of the batches. The numerator indicates the size of a batch, and the denominator refers to the planned volume of delivered material resources on an accrual basis from the beginning of the month. Delivery of the next batch should take place on a working day when the amount of material resources supplied is equal to the required (from the beginning of the month, accrued total).

Type-size of a res-ce	Stock reserve	Size of batch	Indicators of schedule	Daily supply schedule for material resources, one month																							Total, mnth	Opening balance
			Working days	1	2	3	4	7	8	9	10	11	14	15	16	17	18	21	22	23	24	25	28	29	30	31		
			Daily demand, actual	10	10	10	15	15	2	3	5	0	8	12	15	10	10	3	3	5	0	4	8	9	10	2		
			Daily demand, accrued total	10	20	30	45	60	62	65	70	70	78	90	105	115	125	128	131	136	136	140	148	157	167	169	169	
			Schedule	50/	70				50/	120				50/	170								50/	220				
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Figure 3. Schedule for the provision of material resources

This methodology enables stakeholders to keep records of the actual materials provision, monitor the implementation of a plan for provision by time frame and quantity, assess the degree and causes of deviations, promptly adjust daily demand by the accrued total from the beginning of the month, determine delivery date for the next batch, and consider the actual progress of supplies. This table illustrates the methodology, which is highly complex and thereby practically implementable only when IT systems are used. Thus, delivery dates of material resources are more accurately determined, with excess or shortage excluded (Simakova, 2022).

When the described methodology for developing a provision schedule is implemented, a daily demand (or another planned period with constant daily consumption, for example, a week) for them is determined by the release date. In turn, this date is scheduled in accordance with marketing requirements (consumer needs for products in terms of quantity and timing), logistics (transportation), and production (volume of continuous production of mass products).

The actual inventory data, accounting records, and IT data determine the amount of material resources at the beginning of the month. Based on these data, plus the daily (variable) demand of an enterprise for material resources, the delivery time of the first batch D 1 is specified as (Formula 1):

$$M_{st} = \sum_{k=1}^{d} Md_K, \tag{1}$$

where M_{st} is the amount of stored material resources at the beginning of the month, units; *k* is the average daily demand for the *k–th* day; $k = 1, \ldots, K$ is the index of a working day.

In this case, the volume of supply is taken as specified (fixed). The delivery time for the second and subsequent batches is defined as (Formula 2):

$$n_2 = \sum_{K=D1}^{D2} \mathrm{M}d_K \tag{2}$$

$n_3 = \sum_{K=d2}^{d3} Md_K$ etc., where n_i is the batch number equal to the specified volume.

Considering the fact that supplies are measured in batches, the monthly amount of material resources that must be delivered is specified as (Formula 3):

$$M_m = K_n{*}n, \tag{3}$$

where K_n is the number of batches to be delivered per month, and n is the batch volume, units.

Today, most enterprises cooperate with reliable suppliers via framework contracts. Therefore, the issue of determining batch size is important when planning working capital and costs for supply and storage. Although in practice, volumes of batches are most often specified on the grounds of previous experience, knowledge, or even hunch of management, more palpable factors should be taken into consideration. They include capacity of vehicles or containers (transit rate), tight budget, maximum batch size limited by the warehouse capacity, suppliers limiting the batch size by setting minimum and maximum orders, all batches not splitable (rolls, packaging, etc.), fluctuations in demand for materials with dynamic production, supplier running out of the necessary volume, discounts for large volumes, changing prices and possible interruptions in supply, damage, loss, normal wastage, and outdating of materials when a long-term storage of a large batch takes place (Hennet, 1999).

Inevitably, production also suffers from the untimely provision of material resources. For orders to be processed on time, companies have to go with parts made from scarce materials, which entails additional costs for overtime, urgent production of lacking parts in smaller batches, violation of schedules for other productions, etc. Overall, this results in a last-minute rush that is likely to affect the quality of the products. Further, companies may start to run the risk of failing to process the order, which would result in penalties, fines, and the loss of consumers who may flock to competitors.

The predominant criterion for choosing suppliers is not the price or the possibility of deferred payment, as is often the case currently in Russia. Rather, it is the supplier's ability to provide material resources in a timely manner, taking into account all the specifics of consumers: the potential necessity to change their orders by volume, range, completeness, timing, transportation mode, routes, and even order withdrawal. The guidelines presented below were designed on the basis of expert opinions shared by the researchers, including Lukinsky and Strimovskaya (2016), Zharinov (2022), and Dybskaya (2012). To develop a comprehensive system of operational management, it is necessary to:

1. Integrate and synchronise management of material resources with production and sales; efficiently respond to changes in production programmes and adapt to dynamics in demand.

2. Reduce the period of release planning (up to a quarter instead of a year) and, accordingly, the period of demand planning, since an annual contract is likely to lead to excessive purchasing and subsequent penalties for nonacceptance, as provided by the contract. It is essential to provide for quarterly adjustment of supply volumes and/or revision of the delivery schedule in case of significant market changes.

3. Broaden demand planning for integrated product groups, since a drop in demand for some products can be offset by a growing demand for others.

4. Outsource personnel for planning. Provide contracts that would set fines or compensation fees for various types of loss, including lost profits or deviations from the preplanned demand, by a specified %.

5. Negotiate the planned demand with suppliers who can see the bigger market picture in terms of demand and potential fluctuations.

6. Expand the range of supplies to eliminate the risk of disruptions.

7. Increase the frequency of stock control, preferably from once a year to quarterly checks, or even more often.

8. Arrange operational tracking (accounting, control, assessment) and operational regulation of supplies; develop a framework of supplier liability (penalties, payment of damages) for failures.

9. Constantly monitor the emergence of innovative materials.

10. Promptly monitor the financial conditions of suppliers. It may even be appropriate to provide temporary financial assistance in a rough patch. For example, by purchasing a larger batch, acquiring a share in their authorised capital, or purchasing bonds. (Dubolazov, 2017).

To achieve these goals, it is necessary to introduce modern management systems for materials supply, for instance, material requirements planning (MRP), just in time (JIT), vendor managed inventory (VMI), and lean production (LP).

There are two ways to meet the demand for materials. The first is to order them at the exact time they are required. The MRP system operates within that framework. Such a system is applied to plan the purchase of expensive materials, as well as those that are used for manufacturing individual orders, when the deadline is not specified. The second method is to maintain stocks. This is a so-called “at stock” model used for less expensive materials and standard components that are needed on a regular basis, in large volumes, and for different requests. These stocks should be purchased and delivered in such quantities and time that would suffice the demand for them. Typically, companies tend to use both methods.

However, without a universal operational management system for dynamic multi-type production, enterprises are forced to choose between one of the two options below:

1) Apply various systems of operational production management, which significantly impede the planning, accounting, control, and regulation of production;

2) Apply a particular system of operational production management that would allow averaging in calculations (e.g. the daily demand may be taken as a constant), and using statistical accounting units (set, group set, per-day set, conditional unit, etc.) (Konovalova, 2018).

An integrated approach to supply management requires linking operational accounting to the consumption of material resources in production. A matter of fundamental importance here is to establish a solid connection between operational decision-making and the performance of economic stimulation and completion of the processes involved. Four types of reserves to promptly eliminate potential deviations are material, organisational, moral, and time reserves. The operational control system must be flexible enough to respond correctly to any deviations, and still function appropriately with specified reservations. This perspective allows for the classification of all deviations into three groups:

1) Permissible deviations in delivery time, quantity, and quality of material delivered; this should be considered when placing the next purchase order;

2) Deviations that can be eliminated without adjusting schedules; for example, a small percentage of defects in a batch, less-than-a-day delay compensated by insurance stocks;

3) Serious deviations that require additional resources for their elimination or revision of pre-planned schedules.

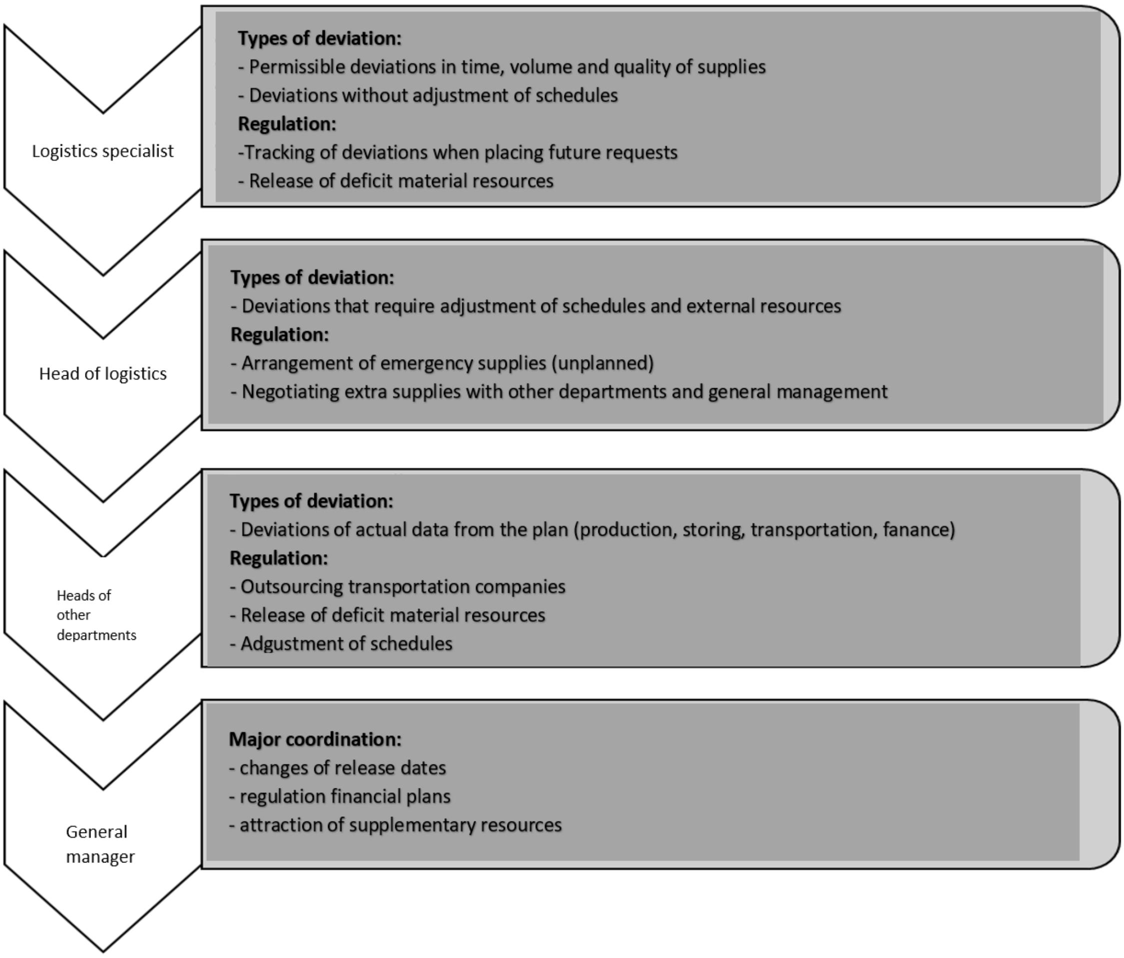

Figure 4. Hierarchical system control and regulation of operational management

This study proposes a hierarchical system of operational control and regulations (Figure 4), in which each level of management specifies types and frames of deviations, timing for their elimination, and fixed reserves (logistics specialist, head of the logistics department, heads of other departments, or general manager). Data on occurring deviations are passed on to higher levels if they cannot be covered by reserves at a lower level. This scheme reduces unnecessary information exchange between management levels, frees administrators at higher levels from current operations, and allows them to focus on long-term planning. The frequency of higher-level managers' interference in subordinates' activities decreases through the hierarchy. Thus, it encourages independence, responsibility, and improvement of the social and psychological climate.

The efficiency of operational management in logistics, especially operational regulation, is largely determined by the timely recorded deviations from the norm, and accurate collection, transmission, and processing of information. Of importance here is the fact that without providing the necessary information in real time, it will be difficult to implement the above-mentioned system and methodology in developing supply schedules. Typically, existing automated control systems are restricted to maintaining daily operational records and shift planning. Of course, it does improve the efficiency of operational management. However, at the same time, this leads to a time lag in regulating production in terms of emerging deviations. Fortunately, at present, multiple digital instruments have created solid grounds for an automated real-time control system to be implemented.

Large-scale digitalisation and the fourth industrial revolution rest on multiple tools: IoT, cyber-physical systems, artificial intelligence, neural networks, cloud and quantum technologies, robotics, 3D printing, and others. To digitalise the entire supply chain (supplier-finished product-consumer), it is necessary to create a common space for communication and information exchange. The integral stages of material supply management include planning demand and quantity of materials to order; search, examination, selection, and verification of suppliers; contract making; operational management of material resources; accounting and logistics control; and operational management of materials supply to different divisions of an enterprise. Digital tools with wide coverage can be selected at all stages (Figure 5).

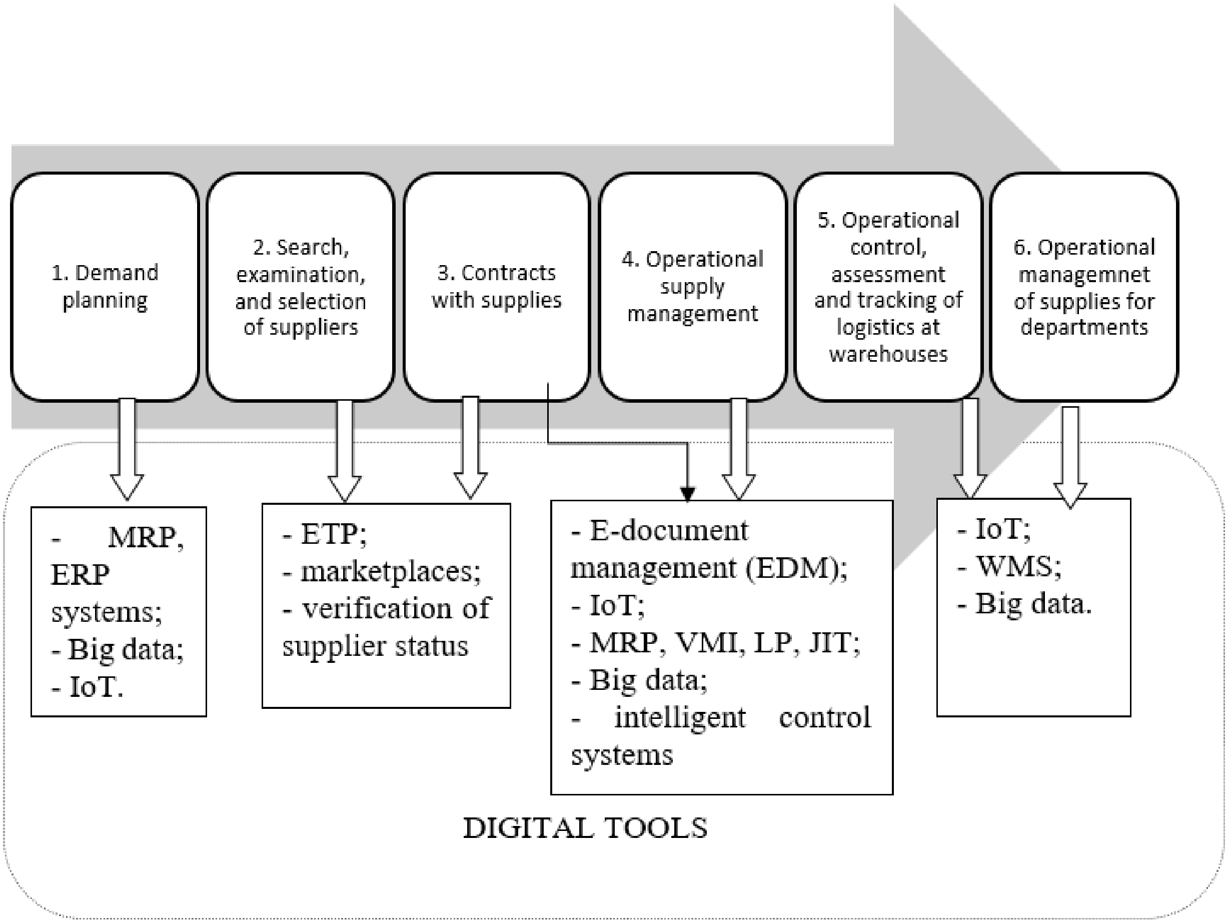

Figure 5. Implementation of digital tools at the main stages of operational supply management

Big data, IoT, electronic document management, etc. are singled out as the main digitalisation tools used in resource management. IoT, for instance, allows operational dynamic regulation of processes associated with logistics in real time. It encourages flexibility of timely response to various "disturbants", both external (new orders, changes in volume, time, or completeness of manufactured products), and internal (changes in availability of resources: materials, technology, output, or reduced equipment performance). Thus, IoT eliminates the notorious drawback of MRP—lack of efficiency and flexibility—which makes IoT a promising development in the digitalisation of logistics (Tokareva et al., 2018).

At the operational level, IoT devices use various sensors to monitor the movement and storage of materials in a warehouse, transport, and materials supply, and the use of equipment and processes associated with manufacturing itself. When combined with information systems and computer resources, IoT shapes the digital logistics system of an enterprise, as well as cyber-physical systems for managing production complexes. This is especially relevant in flexible production systems (Zaychenko et al., 2021). Here, the logistics system is tracked and managed throughout the entire supply chain in real time, which allows for responding to any minor changes as promptly as possible. Further, all stakeholders are able to receive relevant big data on problems that may arise. (Glavee-Geo, 2016). This study articulates promising directions for further comprehensive research in the areas of production, transport, warehouses, and other logistics subsystems.

Another area that is thriving due to the growth of information volumes is cloud technology. SaaS, IaaS, and PaaS cloud computing allow for the processing of huge amounts of data. In 2020, 5G entered the Russian arena. This technology is expected to fulfil the potential of big data, reduce the share of intuitive decision making, capture microtrends in consumer preferences, and ensure timely response to current changes. These all occur due to higher data transfer speeds, ultra-low costs, and heterogeneous network architecture (Grishunin et al., 2019). The implementation of 5G will allow enterprises to introduce synergetic transport systems, create smart port systems, and advance significantly in the development of smart factories.

Such developments as EDM, IoT, network technologies, cyber-physical systems, Big Data, intelligent control systems, and other digitalisation tools contribute greatly to the development of digital twins in logistics. They enable enterprises to simulate and predict the future trends and conditions of products and materials in real time (Bril et al., 2021). The biggest advantage of using digital twins is their ability to ensure the transparency and credibility of logistics operations. Generally, the market literally calls for such prospects due to an unstable competitive environment, force majeure, and COVID-19. Regarding supply management, digital twins are necessary to achieve the following goals:

- Detecting bottlenecks in supply management;

- Testing changes in the design of new supply management models, for example, VMI, JIT, or shifts in inventory management;

- Monitoring risk and predicting potential risks in the long run;

- Testing operations for the short term (Shvedenko and Mozokhin, 2020; Sergeev, 2019).

As a means to increase the efficiency of supply management, IoT seems to be most promising today. At present, Russia considers IoT at the legislative level within the national programme “Digital Economy”. However, “IoT” is only observed there in the concept of building and developing narrow-band wireless communication networks, while it is neglected in procurement management. IoT can help reduce the costs of supply, finished products, and overall costs throughout the entire supply chain.

IoT also creates a significant advantage in decision-making. It is with the help of IoT that data collection in real time becomes possible. It increases the efficiency of business processes, security, and quality. These outcomes prove to be highly relevant, since more than half of logistics employees note the lack of transparency in the supply chain. Over the past 5 years, the share of companies using IoT in supply chains has grown from 2% in 2015 to 7% in 2020. The upward trend continues (Lawal and Rafsanjani, 2022). The annual growth rate of the IoT market is predicted to reach approximately 15–20%. Thus, in 2016, IoT expenditures in various markets amounted to about $700 billion, and by 2020, they exceeded $1 trillion (Khan et al., 2021).

Digital tools allow the creation of a model of digital twins. With the help of artificial intelligence and machine learning, it is possible to create a digital copy of the entire logistics chain. Since digital twins support the whole cycle (purchase-sale), their utilisation increases the accuracy of production planning, reduces the share of defects, and prevents risks associated with some typical bottlenecks. Logically, the identification of risks at early stages reduces operational costs, including those for purchased material resources. Modelling supply chains with changing configurations allows for testing innovations painlessly. For example, it may be applicable to the replacement of suppliers and models of interaction with them (Marmolejo-Saucedo, 2020; Defraeye et al., 2021).

RPA platforms in supply management.

In recent years, the robotic automation of business processes has been experienced in a wide range of industries. Robotic process automation (RPA) is a technology that automates repetitive, long-term, routine business processes by inviting software robots capable of recording and reproducing human actions in an enterprise information system. RPA is a relatively new type of software that reproduces transactional processes based on strictly specified rules. In supply management, software robots serve as a means to reduce the time spent by humans on a large number of repetitive processes, including collecting requests, searching for price information, controlling receipts of commercial offers, checking information on counterparties, tracking the order status, etc. Processes associated with supply generate a large amount of information that could be better and quicker processed if software robots were invited. They are able to extract information about the cost of goods and services, delivery time, and payment terms from supplier documents. With the robotisation of voluminous business processes, the time spent on their implementation is reduced. Subsequently, procurement specialists can redistribute efforts to deal with strategic tasks.

Although RPA technology is often emphasised as easy to implement, in practice, this process can be accompanied by a wide range of issues. According to a survey of 400 senior managers conducted by “Supply Chain Dive”, 38% of RPA implementation projects have not been completed (Anagnoste, 2018). Impediments begin at the stage of selecting the processes to be robotised. The problem is that various sources offer a range of selection criteria that, in fact, are sometimes incompatible. For example, researchers often suggest choosing the most voluminous transactions (Madakam et al., 2019). However, this strategy has been widely criticised. Some authors argue that the RPA system should not handle large-volume tasks. Instead, it should be applied by companies interested in the robotic automation of business processes for medium-sized transactions, since they have a greater business value. A common reason for the inefficiency of software robots is the lack of preliminary arrangements aimed at optimising business processes. In this case, speeding up an inefficient sequence of actions through robotics will only make matters worse. The reengineering of business processes is the most important stage in RPA implementation.

According to Figure 5, the software robot independently extracts information from specifications on the quantity and features of the purchased inventory items, and their price. Thereby, it determines the range of potential suppliers and requests for commercial offers. It is also possible to perform the latter from the procurement department database.

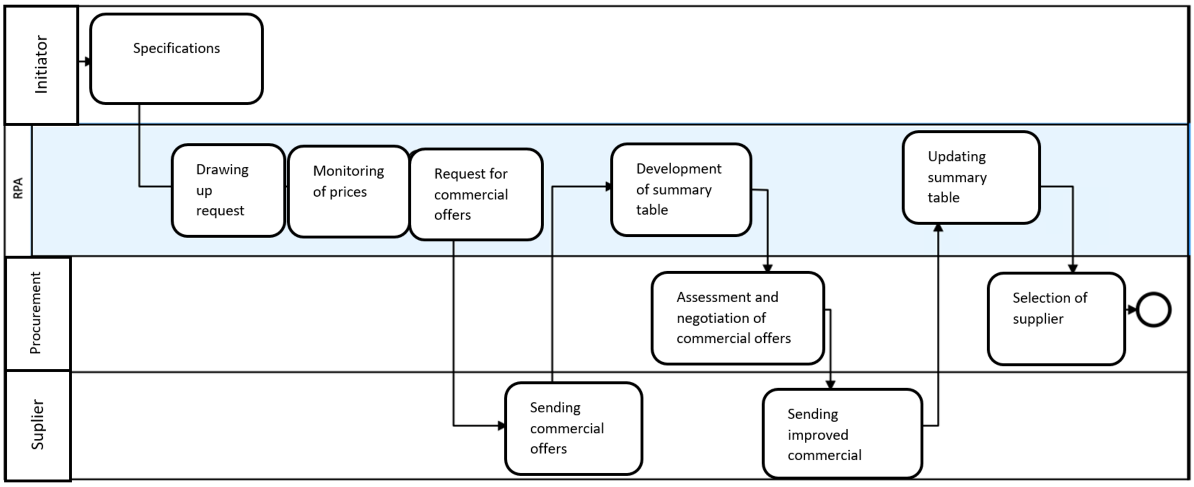

Figure 6. Modelling of supplier selection process assisted by a procurement specialist and a software robot in the BPMN notation (Shapiro, 2022)

A more effective application of RPA requires integration with artificial intelligence, since cognitive decision support systems can allow software robots to carry out more complex business processes. When applied in its traditional mode, the RPA system depends heavily on human participation.

To increase the efficiency of management, it is necessary to identify indicators that allow for controlling the process of provision. It is also important to motivate employees to ensure an uninterrupted supply of materials in compliance with quality and, at the same time, minimise logistics costs. Further, digitalisation is an important optimisation tool for operational management. Therefore, when calculating indicators of management for material resources, the level of digitalisation should be considered. The results of the assessment allow the authors to suggest using the indicators presented in Table 1.

Table 1. Indicators for evaluating the efficiency of digital tools applied in procurement management

Indicator	Formula	Clarification
Indicators of implementation of digitalisation tools		
Share of purchases by Internet tenders/ contests, via ETP (K_T)	$K_T = \frac{N_T}{N_Z}$, where N_t is the number of deliveries placed at the ETP, N_z is the number of deliveries for the period	Reduces time for status verification through preliminary accreditation by ETP; purchase of material resources at a minimum cost
Share of suppliers that use EDM (K_{EDM})	$K_{EDM} = \frac{N_{EDM}}{N_p}$, where N_{EDM} is the number of suppliers who use electronic document management, N_p is the total number of suppliers for the period	Reduces the number of inaccurate documents and saves time for placing an order
Share of deliveries using IoT (K_i)	$K_i = \frac{N_o}{N_z}$, where N_o is the number of deliveries using tracking	Increases efficiency of delivery tracking; checks compliance with delivery conditions
Share of suppliers verified as reliable via online services (K_s)	$K_s = \frac{N_s}{N_p}$, where N_s is the number of suppliers verified online	Reduces decision-making time dedicated to verification of a supplier

The key performance indicator (KPI) system is another hierarchical management system based on goals. KPIs of individual employees or lower-level management should be aimed at achieving the goals of higher-level units and the organisation as a whole by tracking the efficiency of each process.

Traditionally, enterprises calculate a monthly supply plan in value terms with *k* based on the demand for material resources from a monthly perspective.

$$S_k = \sum_{i=1}^{Il} N_{ik} * C_i \,, \tag{4}$$

where $i = 1, \ldots, I$ is the index of the type of material resource; I is the number of purchased units, pcs.; N_{ik} is the number of material resources of the *i*–th type to be delivered in the *k*–th month, pcs.; and C_i is the provision cost of the *i*-th material resource, rub.

Often, S_k works as a specified indicator, for instance, when it is determined by individual orders, aggregated groups of products, specific spare parts, or other types of materials. To increase management efficiency, the percentage of fulfilment of a monthly plan is calculated in value terms P_{kd} for the *d*-th working day from the beginning of the *k*-th month:

$$P_{kd} = C_{kd} / C_k * 100 \,, \tag{5}$$

Where C_{kd} is the cost of materials supply at the *d*–th working day from the beginning of the *k*-th month, equals:

$$C_{kd} = \sum_{i=1}^{I} N_{ikd} * C_i \,, \tag{6}$$

The planned percentage for the *d*-th working day amounts to:

$$P_{kd} = 100 / D_k * 100 \tag{7}$$

When efficient calculations of the above-mentioned indicators are performed, their assessment can be carried out in a timely manner. In other words, decision-making becomes simpler, and material resources are distributed among all the departments with higher accuracy.

5. Discussion

Enormous data collection that must be adequately processed is a typical side effect of digitalisation, which requires highly qualified specialists with outstanding IT skills. As a result, companies are facing the dilemma of whether they need to nurture such workers themselves, or outsource. However, either option requires impressive funds, which are out of reach for many logistics companies. Another limitation of digital solutions is the lack of supporting infrastructure. Warehouse technologies require premises for wireless networks to fix sensors on site, meaning that remote and larger warehouses will require complete or partial modernisation, which again entails impressive costs.

Despite the widely discussed positive aspects of digitalisation, a number of authors (Trittin-Ulbrich et al., 2021; Binsfeld and Gerlach, 2022; Fedotova, 2019) believe that digitalisation entails a range of significant drawbacks. The problem is that with a deeper immersion in the cyber environment when using digital tools, enterprises face new risks associated with data leakage, confidentiality, etc. Apparently, these newly found threats need to be addressed with all due precautions and large investments in updating software and operating systems. Further, all the accumulated big data must be carefully processed and classified so as not to cause incorrect source data grounds for the construction of digital twins and other mathematical and simulation models.

6. Conclusion

The Russian economy is vastly focusing on the development of machinery enterprises and strives to improve digital technologies, increase labour productivity, and enhance import substitution. In today's unstable political and economic conditions, it seems impossible to develop the industry unless operational enterprise management systems are integrated on a large scale. Since the costs of material resources can account for 60% of total costs, operational management systems prove to be key to reducing costs and, less painfully, adjusting to market changes.

Current theoretical and practical research has shown that operational management systems do not take into account the variety of production types and the dynamics of demand. To address these issues promptly, this study proposes a concept for an operational management system and a methodology for drawing up calendar schedules for materials provision in response to demand dynamics (by inventory range, quantity, completeness, and time). As a tool for reducing costs arising from deviations in delivery indicators, the authors developed a hierarchical system of operational control and regulation that specifies fixed types of deviations and defines the volume of reserves and time frame for the elimination of deviations.

Changes in the management of material resources and the implementation of digital tools are the only possible ways to address challenges posed by the fourth industrial revolution, globalisation, increasing automation, and speed to market. The digital tools that are proposed for each stage of operational management are aimed at enhancing the efficiency of control, accounting, and assessment of supply. The combination of these tools enables enterprises to perform more accurate calculations and optimise decision making. Thus, a hierarchical system of KPIs for the proposed operational system was constructed with the aim of ensuring the efficient implementation of new methods and calculation tools. In the long-time, these measures are expected to increase the efficiency of production, timing, and utilisation of material resources.

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