AKADEMIA NAUK STOSOWANYCH
WYŻSZA SZKOŁA ZARZĄDZANIA I ADMINISTRACJI W OPOLU

ACADEMY OF APPLIED SCIENCES
ACADEMY OF MANAGEMENT
AND ADMINISTRATION IN OPOLE

MANAGEMENT OF ASSESSMENT OF RELIABILITY OF SUPPLY CHAINS

ACADEMY OF APPLIED SCIENCES ACADEMY OF MANAGEMENT
AND ADMINISTRATION IN OPOLE

Oleg Zagursky, Tadeusz Pokusa, Mikola Ohiienko, Svitlana Zagurska,
Alona Ohiienko, Liudmila Titova, Ivan Rogovskii

MANAGEMENT OF ASSESSMENT OF RELIABILITY OF SUPPLY CHAINS

Monograph

Opole 2024

ISBN 978-83-66567-64-1

Management of assessment of reliability of supply chains. Monograph. Opole: Academy of Applied Sciences Academy of Management and Administration in Opole, 2024; ISBN 978-83-66567-64-1; pp. 247, illus., tabs., bibls.

Editorial Office:
Academy of Applied Sciences Academy of Management and Administration in Opole 45-085 Polska, Opole, ul. Niedziałkowskiego 18 tel. 77 402-19-00/01
E-mail: info@poczta.wszia.opole.pl

Recommended for publication
by the Academic Council of Academy of Applied Sciences Academy of
Management and Administration in Opole
(Protocol No. 5 of May 20, 2024)

Reviewers
prof. zw. dr hab. Piotr Blaik, prof. dr hab. Henryk Sobczuk,
prof. dr hab. Wacław Romaniuk

Authors of Monograph
Oleg Zagursky, *Tadeusz Pokusa*, *Mikola Ohiienko, Svitlana Zagurska,*
Alona Ohiienko, Liudmila Titova, Ivan Rogovskii

Publishing House:
Academy of Applied Sciences Academy of Management and Administration in Opole, 45-085 Polska, Opole, ul. Niedziałkowskiego 18 tel. 77 402-19-00/01

200 copies

ISBN 978-83-66567-64-1

CONTENT

INTRODUCTION.. 5

CHAPTER 1. THEORETICAL AND METHODOLOGICAL ASPECTS OF RESEARCH RELIABILITY OF SUPPLY CHAINS................................ 8
1.1 Basic definitions of supply chain reliability and their characteristics 8
1.2 Factors influencing supply chain reliability and approaches to its assessment 31
1.3 Methods and capabilities of supply chain reliability assessment................ 56

CHAPTER 2. ECONOMIC AND MATHEMATICAL MODELS OF SUPPLY CHAIN RELIABILITY 88
2.1. Development of a model representation of of supply chain reliability...... 88
2.2 Formation of supply chain reliability models 104
2.2.1 Formation of economic models of supply chain reliability 108
2.2.2 Formation of deterministic supply chain reliability models 116
2.2.3 Formation of stochastic models of supply chain reliability 128
2.2.4 Formation of supply chain reliability simulation models 141
2.3 Multilevel models of supply chain reliability 150

CHAPTER 3. APPLICATION OF ECONOMIC AND MATHEMATICAL MODELS FOR SUPPLY CHAIN RELIABILITY ASSESSMENT IN CONDITIONS OF UNCERTAINTY 167
3.1 Application of reliability assessment models in supplies 168
3.2 Application of reliability assessment models in production and logistics systems 186

3.3 Application of reliability assessment models in transport
and logistics systems 203

CONCLUSIONS 213

REFERENCES 219

INTRODUCTION

The transition to a post-industrial society is marked by cardinal changeschanges that require the development of new methods and approaches in the functioning of society. Logistics as a field of human activity is also undergoing changes. Network, informational, cognitive features of the new economic formation determine approaches to flow management. New requirements appear, the requests of the end consumer become the priority, in connection with which the logistics of individual business processes is replaced by the concept of supply chain management. Given the new economic conditions, an effectively functioning supply chain must meet all the requirements of the economy of a post-industrial society, in particular, a quick response to changes in demand, fulfillment of orders with high quality of service. In this regard, during the construction of modern logistics systems, the policy of selling manufactured goods is replaced by the policy of production of goods for sale or services; constant work is carried out to minimize the terms of passing products through the technological process, reduce groups of resources and processing, reduce all types of downtime and irrational intra-production transportation.

In the modern economy, one of the basic competitive advantages of any organization is the ability to quickly and efficiently satisfy consumer requests in accordance with their requirements. The most important tool in the process of achieving this goal is the logistics orientation of the organization as a whole, since the formation of an effectively functioning logistics system allows for the delivery of the goods needed by the consumer to the right place, time, in the required quantity, of the required quality and with the lowest costs. However, a combination of adverse external factors, both global (wars, pandemics, financial crises, natural disasters, depletion of natural resources and degradation of ecosystems) and purely economic, associated with price fluctuations, arbitrary increases in supply batches, deviations from planned deadlines and production volumes, leads to disruptions or failures in the supply chain, and therefore to reduced supply reliability and increased costs. Due to the existence of many factors that affect each of the participants in the supply chain, its system is prone to variability and is subject to randomness, which directly affects the reliability of the entire supply chain. Accordingly, the question of how to analyze and increase the reliability of the supply chain is becoming more and more relevant and is receiving more and more attention.

However, despite the obvious need to improve the reliability of supply chains, the number of companies paying due attention to this issue is still insignificant. Domestic and foreign specialists in logistics and supply chain management note that in today's unpredictable and changing market environment, the vulnerability of supply chains is constantly increasing. This is due to the fact that logistics systems and supply chains are becoming more complex due to the division of labor, and the more complex the system is and the higher the degree of interdependence of its elements, the more it is exposed to uncontrollable events. In addition, during crises due to network configurations and complexities of business cycles, optimal selection of supply system complexes, as well as complex demand forecasting processes, operational difficulties arise for all participants in supply chains. Therefore, modern business must be prepared for the possible consequences of this kind of outrage and be ready to apply the necessary tools to increase the reliability and sustainability of its own supply chains. Insufficient attention to the problem of improving the reliability and sustainability of supply chains can lead not only to short-term financial losses, but also to the deterioration of the overall perception of the supply chain in the market, which ultimately leads to a decrease in the capitalization of the company and negatively affects the results of operational activities.

INTRODUCTION

Management of the reliability and stability of the supply chain, as a rule, is associated with the choice of one or another tool that allows in specific conditions or for a specific business process to achieve the continuity of its work. Accordingly, increasing the reliability of the logistics system in general, as well as its individual elements, along with the minimization of logistics costs, is one of the directions for increasing the efficiency and sustainability of the supply chain. The main problem of choosing an adequate method of managing the reliability of supply chains is that for both participants and consumers all the main properties of an effective supply chain (failure, economy and security of supply) are equally relevant. Therefore, it is necessary to jointly use the tools of reliability theory, planning methods built on the basis of operations research and risk management methods.

CHAPTER 1.
THEORETICAL AND METHODOLOGICAL ASPECTS OF RESEARCH RELIABILITY OF SUPPLY CHAINS

1.1 Basic definitions of supply chain reliability and their characteristics

At the end of the 20th century, in economically developed countries, in many branches of business, as a result of the continuous improvement of production technologies, such a situation arose when the cost of production reached its minimum. Under such conditions, in order to ensure competitive advantages, there was a need for a new form of business organization, based on the idea of integration and coordination of all business processes along the entire supply chain from the initial acquisition of resources to the final consumer.

Traditionally, a supply chain can be defined as an integrated process in which a number of different business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together to: acquire raw materials, process those raw materials into specified end products, and deliver those end products retailers. Accordingly, the supply chain is a complex multi-structural system with active elements, which functions in the conditions of a dynamic market environment that is constantly developing and changing.

The functioning of supply chains is associated with considerable uncertainty. Sources of uncertainty can be demand fluctuations, forecast errors, resource failure, data inaccuracy, wrong decisions by managers, transmission of false information and misinterpretation of certain events, as well as global disasters such as wars, natural disasters, pandemics or changes in political or natural conditions.

The implementation of the marketing-oriented economic paradigm contributed to the emergence, establishment and development of logistics as a scientific and practical direction of the concept of strategic partnership. Its further development and improvement were reflected in the formation of a new outlook on business, namely the concepts of supply chain management (SCM) and value chain management (CMS), which provide for the presence of effective internal organizational connections of all participants in the chain through which the product moves. and building inter-organizational connections and their management (Fig. 1.1).

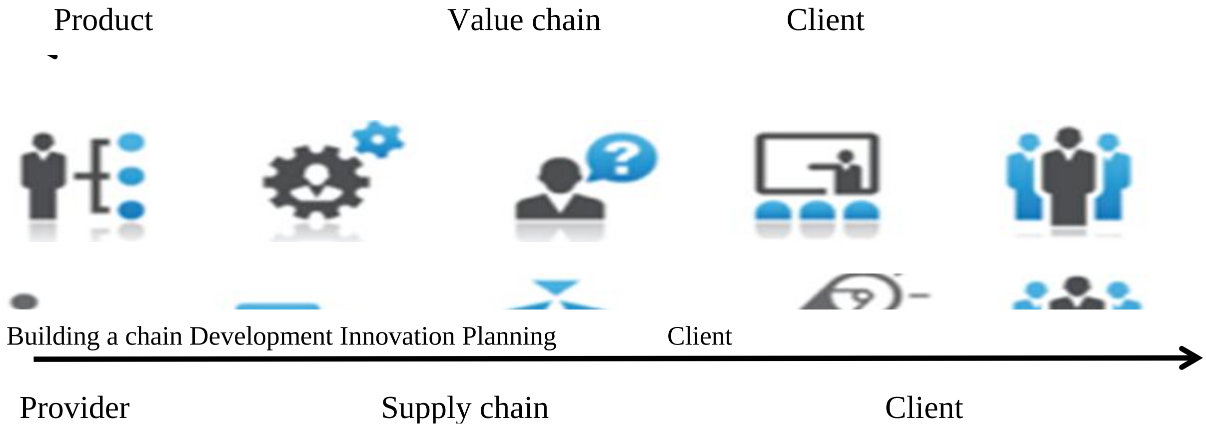


Fig. 1.1 Graphic representation of processes in value chains and supply chains

Source: compiled by the authors

These concepts are somewhat similar, but still slightly different from each other. Thus, according to the definition of World Bank specialists, "ULP is a process by which a company searches for sources and purchases resources (factors of production), processing, production of goods and services, as well as their supply to the consumer. Accordingly, its main task is to satisfy consumer demand for the most efficient use of resources, including labor, warehouse stocks, leftovers and the potential for product sales." And ULSV, from the point of view of business organization, "includes a set of productive (valuable) actions carried out by capital and labor resources (or firms and employees) at the entire stage from the "birth" of a product or service to their final consumption and beyond.

And as noted by I. Feller et al. "Supply chains are focused at the beginning of the production process and aim to integrate the processes of suppliers and manufacturers, in value chains are focused at the end of the production process andaimed at creating value from the consumer's point of view"[1].

Accordingly, the development of supply chains and value chains led to a "revolution" in the theory of trade, which was previously based only on the principle of trade between countries only in finished products. Today, the production process can be divided into segments, each of which corresponds to a separate task, and which can be performed in different countries, where companies add value to the final product. And the development of Internet trade, the entry into the market of online aggregators, national and global trading platforms forms a fundamentally new configuration of the chain of creation of added value. Within which the dominant position begins to be occupied by digital links that do not have a product, but solve the task of attracting a client base, which allows them to retain a significant percentage of added value. And the very concepts of "value chain" and "supply chain" are so closely related to each other that, practically, they consider the same process, but from different points of view. A supply chain describes the flow of resources from a supplier to a consumer, while a value chain describes the flow (movement) of value (from the consumer's perspective). And if the consumer sees no value in what the supply chain offers, there will be no demand. And if the supply chain cannot deliver resources that are valuable to the consumer (at a price the consumer is willing to pay), then there will be no movement of those resources.

Consequently, the development of ideas, methods and means of supply chain management led to the emergence of new generation systems based on a qualitatively new technological environment and a higher level of integration of processes and hierarchical levels of the systems themselves. Customers are

---

[1]Feller I., Glasmeier A., Mark M. Issues and perspectives on evaluating manufacturing modernization programs. Research Policy, 1996, 25(2), 309-319.

increasingly interested in reducing the duration of order fulfillment in combination with high quality customer service. These requirements are no longer measured in weeks or days, but in hours and even minutes. It is possible to single out directions in which the transition from the concept of ERP (organizational strategy for the integration of production and operations) to the concepts of the SCM class takes place:

– increasing the degree of detailing during the planning of logistics capacities;

- the use of the latest IT, which allows simultaneously to combine an increase in the degree of detail of the customer's requirements with the management of orders in real time;

– management of material flows in conditions of restrictions on material resources and capacities;

– formation of distributed databases at the same time for many enterprises included in the technological chain;

– improvement of the state of control and feedback in the form of solving the tasks of accounting for the actual state of stocks and tracking of supply (transportation) processes;

– a dynamic integrated approach to managing information about the life cycle of products.

The appearance of highly integrated management systems became a manifestation of a new level of quality in the development of technological resources in management. They began to integrate almost all spheres of activity of the chain: distribution, transportation, procurement, going beyond the framework of traditional functional areas of organizations. However, the main goal of the supply chain as a technical and economic system is to ensure maximum profit for each partner - a participant in the supply chain. This can be achieved by optimizing the consumption of the six main resources – space, time, materials, labor, energy and money – and ensuring the reliability of these processes over a long period of time when creating and operating a supply chain. And it is reliability and safety that has become a trend in scientific and practical developments in supply chain management in recent years, especially against the background of permanently occurring global disasters (pandemics, wars, natural disasters, financial crises, etc.).

Increasing the reliability of the logistics system in general, as well as its individual elements, along with the minimization of logistics costs, becomes one of the directions for increasing the efficiency of the logistics system. The growing number of publications devoted to the reliability, sustainability and security of supply chains is evidence of the exceptional urgency of this problem. In particular, in recent years, various aspects of the problem of increasing the reliability of supply chains have been considered in many scientific works[2].

Supply chains, as complex systems, are formed from many interacting components (subsystems) and therefore acquire new properties that cannot be reduced to the superficial properties of the subsystem. It is obvious that in the supply chain it is necessary to distinguish between links (participants of the supply chain) and elements (operations performed in it). This breakdown allows you to consider a specific supply chain as a collection of companies and the operations they perform, which allows you to assess its reliability. The reliability of each component affects the reliability of the entire supply chain. The number of indicators for evaluating the reliability of the supply chain can vary from one to

---

[2]Ayan, B.; Guner, E.; Son-Turan, S. Blockchain Technology and Sustainability in Supply Chains and a Closer Look at Different Industries: A Mixed Method Approach. Logistics 2022, 6, 85. https://doi.org/10.3390/logistics6040085 , Eirill Bø, Inger Beate Hovi, Daniel Ruben Pinchasik, COVID-19 disruptions and Norwegian food and pharmaceutical supply chains: Insights into supply chain risk management, resilience , and reliability, Sustainable Futures, Volume 5, 2023, 100102 , George Kankam, Evans Kyeremeh, Gladys Narki Kumi Som, Isaac Tetteh Charnor, Information quality and supply chain performance: The mediating role of information sharing, Supply Chain Analytics, Volume 2, 2023, 100005,Martins, VWB,Anholon, R.,Leal Filho, W.andQuelhas, OLG(2022), "Resilience in the supply chain management: understanding critical aspects and how digital technologies can contribute to Brazilian companies in the COVID-19 context",Modern Supply Chain Research and Applications, Vol. 4 No. 1, pp. 2-18.https://doi.org/10.1108/MSCRA-05-2021-0005, Lee, I.; Mangalaraj, G. Big Data Analytics in Supply Chain Management: A Systematic Literature Review and Research Directions. Big Data Cogn. Comput. 2022, 6, 17.https://doi.org/10.3390/bdcc6010017, von Berlepsch, D., Lemke, F. & Gorton, M.The Importance of Corporate Reputation for Sustainable Supply Chains: A Systematic Literature Review, Bibliometric Mapping, and Research Agenda. J Bus Ethics (2022).https://doi.org/10.1007/s10551-022-05268-x,

several for different components of the chain (or even the entire supply chain). It is clear that the greater the number of components, the more difficult the reliability calculation will be.

Under such conditions, the most important tasks of studying the reliability of the supply chain are:

- determine the main conceptual apparatus;

- justify criteria and indicators of the reliability of supply chains and their elements, taking into account technical, organizational and technological, economic, social and environmental factors;

– to develop models of functioning of supply chains (functional and structural);

– develop models and methods of analyzing the reliability of supply chains;

- to propose recommendations for ensuring the given requirements for the reliability of supply chains.

In works devoted to issues of reliability and safety in the management of supply chains, the terms and definitions of the conceptual apparatus of the theory of reliability (adaptability, reproducibility, reliability, safety, stability, reliability) are given, the analysis of which shows that, firstly, their interrelationship is not is always transparent, and secondly, different interpretations of the same concept sometimes contradict each other. Thus, the adaptability of the supply chain is also defined as "the dynamic ability of the firm to change from the point of view of technologies, products and strategies"[3]and more broadly as "the ability of supply chain partners to integrate their processes to provide competitive advantages over other supply chains"[4].

[3]Eckstein D., Goellner M. , Blome C. , Henke M. The performance impact of supply chain agility and supply chain adaptability: The moderating effect of product complexity International Journal of Production Research, 2015, 53 (10), 3028-3046.

[4]Iranmanesh M., Maroufkhani R., Asadi S., Ghobakhloo M., Dwivedi YK, Tseng M. Effects of supply chain transparency, alignment, adaptability, and agility on blockchain adoption in supply chain among SMEs, Computers & Industrial Engineering, Volume 176 , 2023, 108931.

At the same time, resilience is also "the ability of the supply chain to eliminate the consequences of failures"[5], and "the ability to cope with disruptions due to quick and cost-effective response"[6].

Reliability is also characterized by "the ability of the supply chain to function without failures for a certain time in accordance with the terms of the contracts between the participants of the chain"[7]and "the ability to react and recover from inevitable disruptions"[8].

Security also acts as "resistance to a deliberate act of illegal interference designed to harm the supply chain[9]", and as "avoiding potential losses from counterfeiting for the benefit of both buyers and manufacturers"[10].

Sustainability is also defined as "a concept implemented by finding the best and most expedient solutions to problems as they arise in supply chains"[11]and as "the ability to withstand crises, recover and reorganize in response to them"[12], and as "the desired balance between vulnerability and opportunity in which firms are expected to be most profitable in the long run"[13], and more comprehensively as "the management of material, information and capital flows, and even cooperation between companies in the supply chain, taking into account the objectives of all

---

[5]Niamat Ul, Fazio SA, Lawrence J., Gonzalez E., Jaradat R., Alvarado MS, Role of systems engineering attributes in enhancing supply chain resilience: Healthcare in context of COVID-19 pandemic, Heliyon, Volume 8, Issue 6, 2022 , e09592.

[6]Kochan C., Nowicki D. Supply chain resilience: a systematic literature review and typological framework. International Journal of Physical Distribution & Logistics Management. 2018. 48. 10.1108/IJPDLM-02-2017-0099.

[7]Lohmer J., Ribeiro da Silva E., Lasch, R. Blockchain Technology in Operations & Supply Chain Management: A Content Analysis. Sustainability 2022, 14, 6192.https://doi.org/10.3390/su14106192.

[8]Li Y., Zobel CW, Seref O., Chatfield D. Network characteristics and supply chain resilience under conditions of risk propagation, International Journal of Production Economics, Volume 223, 2020, 107529.

[9]Sahoo S., Kumar S., Sivarajah U., Lim WM, Westland JC, Kumar A. Blockchain for sustainable supply chain management: trends and ways forward. Electron Commerce Res. 2022 May 27:1–56. doi: 10.1007/s10660-022-09569-1

[10]Linton JD, Boyson S., Aje J. The challenge of cyber supply chain security to research and practice – An introduction, Technovation, Volume 34, Issue 7, 2014, 339-341

[11]Ibne HNU, Fazio SA, Lawrence E. DR J.-M., Gonzalez S., Jaradat R., Alvarado MS Role of systems engineering attributes in enhancing supply chain resilience: Healthcare in context of COVID-19 pandemic, Heliyon, Volume 8 , Issue 6, 2022, e09592.

[12]Martin-Breen JM Anderies Resilience: A Literature Review. Bellagio Initiative, Brighton: IDS. 2011, 64.

[13]Pettit TJ, Fikse J., Croxton KL Ensuring supply chain resilience: development of a conceptual framework. J. Business Logistics 2010, 31, 1–21.

three dimensions of sustainable development, i.e. economic, environmental and social, arising from customer and stakeholder requirements"[14].

Reliability as "the property of the supply chain to keep within the established limits the value of all its characteristics and elements"[15], and as "the state of the supply chain, under which its functioning corresponds to the terms of the contracts concluded between the participants"[16], and as "the probability of meeting the requirements of the end user in compliance with the conditions of time, quantity and quality"[17], and as "the probability of performing the necessary functions (the efficiency of order fulfillment in terms of meeting delivery deadlines; the quality of the services provided; the range of products; aggregate costs) in a certain time interval"[18].

At the same time, in a number of other studies, the reliability of the supply chain is considered as a factor contributing to the development of a new paradigm of planning and management of limited resources. Which in turn, when considering the reliability of the supply chain, requires an approach compatible with the science of sustainable development19. After all, from an ecological point of view, a reliable product with a long service life, which helps to save resources by preventing the production of new products at the initial stages, reducing logistics costs and reducing the number of stocks, is also a sustainable product[20].

According to this view, reliability, as a fundamental factor in the optimal combination of strategies for quality customer service and accurate forecasting of

---

[14]Seuring S., Müller M. From a literature review to a conceptual framework for sustainable supply chain management. J. Cleaner Production 2008. 16, 1699-1710.

[15]Raja Santhi A., Muthuswamy P. Influence of Blockchain Technology in Manufacturing Supply Chain and Logistics. Logistics 2022, 6, 15. https://doi.org/10.3390/logistics6010015

[16]MacCarthy B., Ahmed W., Demirel G. Mapping the supply chain: Why, what and how?, International Journal of Production Economics, Volume 250, 2022, 108688]

[17]Zhang M., Chen J., Chang SH., An adaptive simulation analysis of reliability model for the system of supply chain based on partial differential equations, Alexandria Engineering Journal, Volume 59, Issue 4, 2020, 2401-2407

[18]Zagurskiy O., Pivtorak M., Bondariev S., Demin O., Kolosok I. Methods of reliability management in supply chain. Proceedings of the 22nd International Scientific Conference Engineering for Rural Development 24-26.05.2023 Jelgava, LATVIA. 76-84.

[19]Brown S.The End of Reliability.Journal of Water Resources Planning and Management, 2010, 136, 143-145

[20]Bracke S., Inoue M., Ulutas V., Yamada T. CDMF-RELSUS Concept: Reliable and Sustainable Products–influences on Design, Manufacturing, Layout Integration and Use Phase, Procedia CIRP, Volume 15, 2014, 8-13.

system failures, contributes to more efficient use of all resources[21]. This approach is supported by S. Amirian, M. Amiri and MT TaghaviFard,who stated in their research analysis that a change in the level of reliability, in addition to a change in total cost, also changes the carbon emission levels of the entire reverse supply chain[22], and D. Basu and M. Lee, who argue that the practice of ensuring reliability in supply chains acts as a catalyst for achieving sustainable results[23]. Moreover, M. Gobakhlu et al. found that only the simultaneous implementation of sustainability and reliability paradigms makes it possible to fully reveal the synergistic potential of the supply chain and bring more benefits than when they are implemented separately from each other[24].

We can state that in general, the intersection between sustainability and reliability and their relationship with business continuity management and sustainable development are becoming important issues for modern scientific communities and business[25]. Such integration during the design of the supply chain network can be considered as a difficult but relevant criterion. After all, from the point of view of system optimization, design decisions in the field of sustainability and reliability of the supply chain are interconnected, so the general problem can be considered as a problem of simultaneous optimization in these areas of design.

For the characteristics of the reliability of the supply chain, the conceptual apparatus inherent in the classical theory of reliability (Table 1.1) is also widely

[21]Karevan A., Tee KF, Vasili M. A reliability-based and sustainability-informed maintenance optimization considering risk attitudes for telecommunications equipment. International Journal of Quality & Reliability Management. ahead-of-print. 2020. 10.1108/IJQRM-04-2020-0114.

[22]Amirian S., Amiri M., TaghaviFard MT 'The convergence between sustainability and reliability in the design of supply chain: a systematic literature review', Journal of Engineering in Industrial Research, 2023. 4(1), 1-8. doi: 10.22034/jeires.2023.1.1.1

[23]Basu D., Lee M. A combined sustainability-reliability approach in geotechnical engineering. In Risk, Reliability and Sustainable Remediation in the Field of Civil and Environmental Engineering. 2022. 379-413.

[24]Ghobakhloo M., Iranmanesh M., Mubarak M., Mubarik M., Rejeb A., Nilashi M. Identifying Industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values. Sustainable Production and Consumption. 2022. 33. 10.1016/j.spc.2022.08.003.

[25] Corrales-Estrada AM, Gómez-Santos LL, Bernal-Torres CA, Rodriguez-López JE Sustainability and Resilience Organizational Capabilities to Enhance Business Continuity Management: A Literature Review. Sustainability 2021, 13, 8196. https://doi.org/10.3390/su13158196

used in the scientific literature, in which the key concept of the theory of system reliability is the concept of failure, which is associated as the loss of the system or its element of the ability to perform its functions. And for the supply chain, a failure is an event that consists in non-fulfillment of obligations to supply goods under any clause of the contract, which is a risk factor (time, volume, etc.) due to failures in the supply chain. In this sense, it is advisable to consider the supply chain not from the traditional object-functional positions (supplier, manufacturer, intermediary, etc.), but from the process-operational one, i.e. in the form of a sequence of processes for the focal company to fulfill contractual obligations regarding the supply of goods from the supplier to the final consumer (planning → procurement → production → delivery → return).

Table 1.1 – Basic terms and definitions of reliability theory

Term	Definition
Reliability	The property of a technical object to keep its characteristics (parameters) within certain limits under operating conditions
Refusal	An event after which the characteristics of a technical object (parameters) go beyond the permissible limits
Efficiency	The condition of the object, according to which it meets all the requirements established by regulatory and technical documentation
Efficiency	The state of the object in which it is able to perform the specified functions, maintaining the values of the main parameters established by the scientific and technical documentation

Limit state	The state of the object in which its intended use is unacceptable or impractical
Work up	The duration or scope of the object's work, measured in units of time, the number of load cycles, mileage, etc.
Working on rejection	The operation of the object from the beginning of its operation to the occurrence of the first failure
Technical resource	The operation of the object from the beginning of its operation (or recovery after repair) to the transition to the limit state
Reliability	The ability of the object to continuously maintain its working capacity for some time or some working time
Reservation (structural)	A method of increasing reliability by including backup units capable of performing its functions in the event of failure of the main device

Source: compiled on the basis of scientific sources

Accordingly, failure of the supply chain should be understood as the performance of a certain action in the process of functioning of the system with errors or violations that cause certain costs or violations in the performance of subsequent actions. And the main indicators of supply chain reliability should be:

– the probability of trouble-free operation of the supply chain;

– the renewability of the supply chain;

– costs for maintaining the reliability of the supply chain.

And if the probability of trouble-free operation Pt during time t is taken as a quantitative measure of reliability and we know the distribution density f(t) for the period of trouble-free operation, then we will get a conditionally general reliability criterion:

$$P_{(t)} = \int_t^{\infty} f(t)dt, \tag{1.1}$$

However, in supply chains, several processes occur simultaneously that can lead to failure, therefore, for an adequate assessment of reliability indicators, they must be based on a logical model of the occurrence of failures. Therefore, models of failures in supply chains can be based on three types of dependencies between processes that lead to failures:

1) processes xi(t), which in different elements of the system (or in one element), lead to the occurrence of independent failures;

2) processes yi(t) that do not lead to failure due to reaching limit states and are the causes of other processes xi(t) that lead to failures.

3) processes xi(t) that lead to failures, which develop depending on whether other processes yi(t) that do not lead to failure reach a certain state.

For the first type of failures, it is assumed that A destructive processes occur in the system, each of which can lead to the failure of a system element, with the probability density fi(t)

$$f(t) = \sum_{i=1}^{A} \frac{f_i(t)}{F_i(t)} \prod_{i=1}^{A} [1 - F_i(t)], \tag{1.2}$$

where: Fi(t) is the probability distribution function of service failures.

The given formula determines the density of the distribution of minimum values A of random variables.

Along with reliability, a special place in the theory is given to the category "stability" (from the Latin Stabilis-stable) in the theory of reliability of systems. When synthesizing systems, ensuring stability and a given margin of stability is a primary requirement. Stability analysis is designed to answer the following question: Is the supply chain able to return to the planned (standard) state or remain within a certain range of permissible deviations for a certain time interval in case of deviation from the planned state under the influence of various disturbing factors?

Such factors-events that significantly affected global supply chains in the 21st century include: the global financial crisis of 2007-2008, the US-China trade war, the COVID-19 pandemic, and the russian-Ukrainian war. During the coronavirus pandemic, supply chain resilience researchers have mainly focused on the localization of supply chains[26], general behavioral changes and the possibility of transition to greater sustainability[27], as well as problems of social stability[28]. Which in turn raised further research questions about the future of just-in-time practices, industrial structures and storage, and the associated energy losses and waste due to overstocking. And Russia's full-scale invasion of Ukraine raised the issue of increasing risks and, accordingly, decreasing the level of reliability and stability of global supply chains[29]. The war's negative impact on food supply chains affected production, supply, processing and logistics, and contributed to significant shifts in demand between countries dependent on food imports from Ukraine.

[26]Bodenheimer M., Leidenberger J. COVID-19 as a window of opportunity for sustainability transitions? Narratives and communication strategies beyond the pandemic. Sustain. Sci. Pract. Policy. 2020. 16, 61-66.

[27]Fischedick M., Schneidewind, U. The Corona crisis and climate protection-keeping long-term goals in mind. Sustainability Management Forum | Sustainability Management Forum. 2020. 28, 77-81.; Lopes de Sousa Jabbour AB, Chiappetta Jabbour CJ, Hingley M., Vilalta-Perdomo EL, Ramsden G., and Twigg, D. Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic : lessons and trends. Modern Supply Chain Res. 2020. Appl. 2, 117-123.; Sarkis J., Cohen MJ, Dewick P., Schröder P.. A brave new world: Lessons from the COVID-19 pandemic for transitioning to sustainable supply and production. Resourc. Conserv. Recycling 2020. 159:104894.

[28]Anderson JD, Mitchell JL, Maples JG Invited Review: Lessons from the COVID-19 Pandemic for Food Supply Chains. Appl. Anim. Sci. 2021, 37, 738-747.; Majumdar A., Shaw M., Sinha SK. COVID-19 debunks the myth of socially sustainable supply chain: a case of the clothing industry in South Asian countries. Sustain. Production Consumption 2020. 24, 150-155.

[29]Cui L., Yue S., Nghiem XH., Duan M. Exploring the risk and economic vulnerability of global energy supply chain interruption in the context of Russo-Ukrainian war, Resources Policy, Vol. 81, 2023, 103373.; da Costa JP Silva ., AL, Barcelò D., Rocha-Santos T., Duarte A. Threats to sustainability in the face of post-pandemic scenarios and the war in Ukraine, Science of The Total Environment, Volume 892, 2023, 164509.; Ben Hassen T., El Bilali H. Impacts of the Russia-Ukraine War on Global Food Security: Towards More Sustainable and Resilient Food Systems? Foods 2022, 11, 2301.https://doi.org/10.3390/foods11152301.;Jagtap S., Trollman H., Trollman F., Garcia-Garcia G., Parra-López C., Duong L., Martindale W., Munekata PES, Lorenzo JM, Hdaifeh A. et al. The Russia-Ukraine Conflict: Its Implications for the Global Food Supply Chains. Foods 2022, 11, 2098.https://doi.org/10.3390/foods11142098;Welsh C. The Russia-Ukraine War and Global Food Security: A Seven-Week Assessment, and the Way Forward for Policymakers. CSIS. 2022.URL.https://www.csis.org/analysis/russia-ukraine-war-and-global-food-security-seven-week-assessment-and-way forward#:~:text=Food%20price%20increases%20due%20to,percent%20of%20their%20wheat%20imports

The pandemic and the russian-Ukrainian war have prompted a demand for research on the long-term consequences of major disruptions in supply chains, which can be caused by natural disasters, political conflicts, terrorism, sea piracy, economic crises, destruction of information systems or infrastructure facilities. Such disasters cause a ripple effect in the supply chain, where changes occur at a structural level, meaning they are not immediately visible, but recovery is possible in the medium to long term.The reasons for the ripple effect of disruptions in supply chains lie in the phenomenon of outsourcing and offshoring of activities, or can be explained by the concentration of activities in industrial areas, where many suppliers are simultaneously affected by negative factors. In addition, global supply chains are highly dependent on existing transportation infrastructure.

"Make or buy" is a strategic decision that determines whether the components will be produced by the company itself or by subcontractors. Such strategic decisions may be related to the issue of existing competencies or specialization of companies, which may even have their own suppliers who prepare certain modules or systems and deliver them to the assembly line at the moment when they are needed. Decisions within the framework of the "make or buy" model affect the overall strategy for the formation of internal value, and therefore the production strategy.

It should be noted that the peculiarity of sustainability analysis is the controlling influences and externalities (both positive and negative) that are formed by a person, not a machine, and therefore the general dependence on subjective (human) factors. In relation to supply chains, this influence is enhanced by the combination of centralized and decentralized management, i.e. the need to combine the governing influences of companies participating in supply chains, whose interests may be different. This means that in the case of the supply chain exiting the equilibrium state, the search for a new equilibrium state is carried out taking into account the decentralized balancing of the interests of all supply chain participants within the general global criteria of the efficiency of a particular supply chain.

The presence of mechanisms built into the management circuit, containing elements of personalistic uncertainty (subjectivism), fundamentally distinguishes the production and logistics system from the physical one (at least within the framework of classical physical theory). This explains the need for some expansion of the concept of sustainability for supply chains. If in a physical system, stability is determined exclusively by internal characteristics (parameters) under some pre-accepted restrictions, then in supply chains it is the composition of organizational and technological parameters and characteristics of control units that determines the property of stability. In this sense, the property of stability turns out to be related to the scope of the area of possible controlling influences, the expansion of which leads to its increase.

However, with drastic changes in this field, the system becomes different, acquires new properties and parameters, and, therefore, other areas of stability. Such a change in the system can be represented as a jump-like change in its trajectory in the state space. Such behavior is investigated in the theory of dynamic systems using the concept of a bifurcation point and the corresponding conceptually different instrumental apparatus. It follows from this that the analysis of the dynamic properties of supply chains (failure, reliability, stability, etc.) should be carried out within the predefined limits of changes in structural parameters and output variables, since at different sections of the trajectory in the space of states (between the bifurcation points) the supply chain, in general, has different dynamic properties.

Stability has a pronounced dynamic character and is directly related to the factors of uncertainty of the external and internal environment. Stability characterizes the ability of the system to return to its original state and remain within the permissible limits of functioning under the influence of disturbing factors at a certain time interval. If the system does not return to the acceptable limits of functioning within a given time interval, then the system is said to have lost stability. At the same time, it is important to emphasize that the stability of the system is always determined in relation to certain classes of disturbances.

Analysis of the stability of supply chains is carried out at some finite time interval, since the impact of disturbing factors and the manifestation of their consequences on the functioning of the supply chain has certain time lags. The state of the supply chain at a certain point in time can be characterized using a special scale in terms of fuzzy logic, for example, stable, relatively stable, dangerous. An example of a dangerous situation is a situation in which the combination of external and internal factors of the functioning of the supply chain is such that any small disturbance can cause the supply chain to go out of balance. In fig. 1.2. the main aspects of supply chain sustainability analysis are presented.

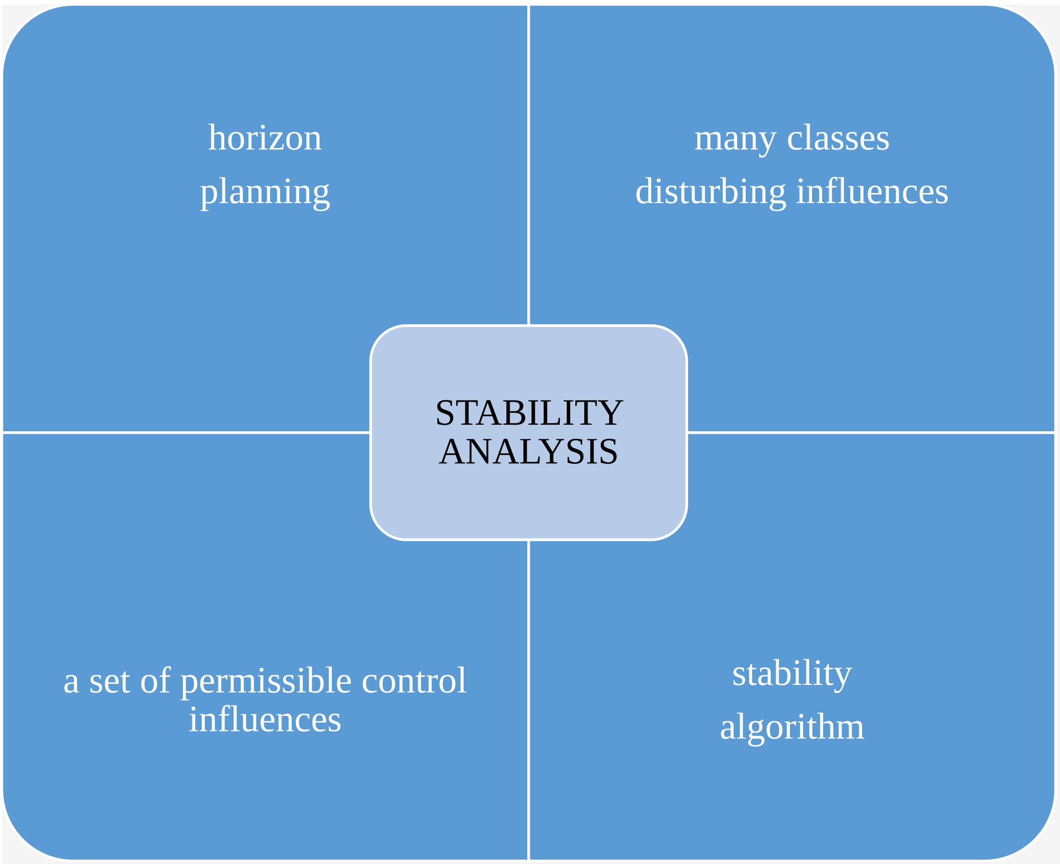


Fig. 1.2 Main aspects of supply chain sustainability analysis

Source: compiled by the authors

The analysis of the stability of supply chains is especially necessary in those cases where it is not possible to build stochastic models of risk factors. It allows you to choose a plan with the necessary guarantee of execution, identify bottlenecks in the plan and measures to strengthen them, as well as develop scenarios to support operational decisions regarding the reconfiguration of supply chains based on the analysis of key performance indicators and acceptable deviations of plan parameters.

Accordingly, sustainability can be considered as a category and indicator for supply chain planning and operational management. The involvement of this apparatus in the model of supply chain management, in addition to the development of theoretical foundations, has practical significance, in particular:

– improving the quality and accuracy of planning and management;

– support for decision-making by management at all levels of planning, monitoring and regulation of supply chains;

– comprehensive analysis of supply chains, forecasting and development of strategic, tactical and operational decisions.

Comprehensive accounting of uncertainty factors using stability analysis allows to improve the quality of supply chain reliability management models due to adequate display of properties and parameters of the external and internal environment. In addition, the use of this device provides additional opportunities for analysis and forecasting of processes in supply chains, as well as improving the quality of production of control influences in conditions of uncertainty.

Thus, despite the fact that the conceptual apparatus, theory and methodology of managing the reliability, safety and sustainability of supply chains have largely been formed, there is currently no unity in the definition of concepts, approaches and interpretations of the reliability of supply chains. Therefore, in recent years, quite a lot of works have appeared in which the dependencies between the processes occurring in logistics systems, which lead to service failures similar to those found during the study of technical systems, are investigated, and the classification of failures in supply chains is given[30].

The classifications provided by various authors, of course, cannot cover all the characteristics of failures inherent in supply chains. Therefore, it is necessary to adapt part of the classification from the theory of reliability of technical systems and supplement it taking into account the specifics of supply chains. For example, supply chains are not characterized by breakdowns in the sense in which they are used in technical systems. An essential feature of failures in supply chains is that they relate to physical processes and many of them cannot be corrected by adjusting plans. Therefore, the primary tasks in the development of the theory of reliability of supply chains are the clarification of the main terms and definitions, as well as the creation of their detailed classifications.

So, by supply chain security we mean the function of SLM that focuses on managing the risks of external suppliers, vendors, logistics and transport. Its purpose is to identify, analyze and reduce risks that arise when working with other organizations within the supply chain. Supply chain security includes both the physical security of products and the cyber security of software and services.

The sustainability of the supply chain is its ability to return to its initial state and remain within the acceptable limits of functioning under the influence of disturbing factors for a certain time interval.

[30]Alruqi M., Baumers M., Branson DT, Girma S. The Challenge of Deploying Failure Modes and Effects Analysis in Complex System Applications–Quantification and Analysis. Sustainability 2022, 14, 1397.https://doi.org/10.3390/su14031397; Benedito E., Martínez-Costa C., Rubio S. Introducing Risk Considerations into the Supply Chain Network Design. Processes 2020, 8, 743.https://doi.org/10.3390/pr8060743; Gurtu A., Johny J. Supply Chain Risk Management: Literature Review. Risks 2021, 9, 16.https://doi.org/10.3390/risks9010016; Holgado de Frutos E, Trapero JR, Ramos F. A literature review on operational decisions applied to collaborative supply chains. PLoS One. 2020 Mar 13;15(3):e0230152. doi: 10.1371/journal.pone.0230152.; Son C. Supply Chain Risk Management: A Review of Thirteen Years of Research. American Journal of Industrial and Business Management, 2018, 8, 2294-2320. doi:10.4236/ajibm.2018.812154; Lei Kh., MacKenzie CA Assessing risk in different types of supply chains with a dynamic fault tree, Computers & Industrial Engineering, 2019, Volume, 137, 27. 106061;Zagurskiy O., Pivtorak M., Bondariev S., Demin O., Kolosok I. Methods of reliability management in supply chain. Proceedings of the 22nd International Scientific Conference Engineering for Rural Development 24-26.05.2023 Jelgava, LATVIA. 76-84.

AND under the reliability of the supply chain, taking into account the requirements of specific chain participants, which are usually fixed by the contract - a property that characterizes its ability to function, fulfilling all the requirements of the contract without exceeding the planned costs. That is, a set of such criteria as: the efficiency of order fulfillment from the point of view of meeting deadlinessupply, quality of services provided, range of products and total costs.

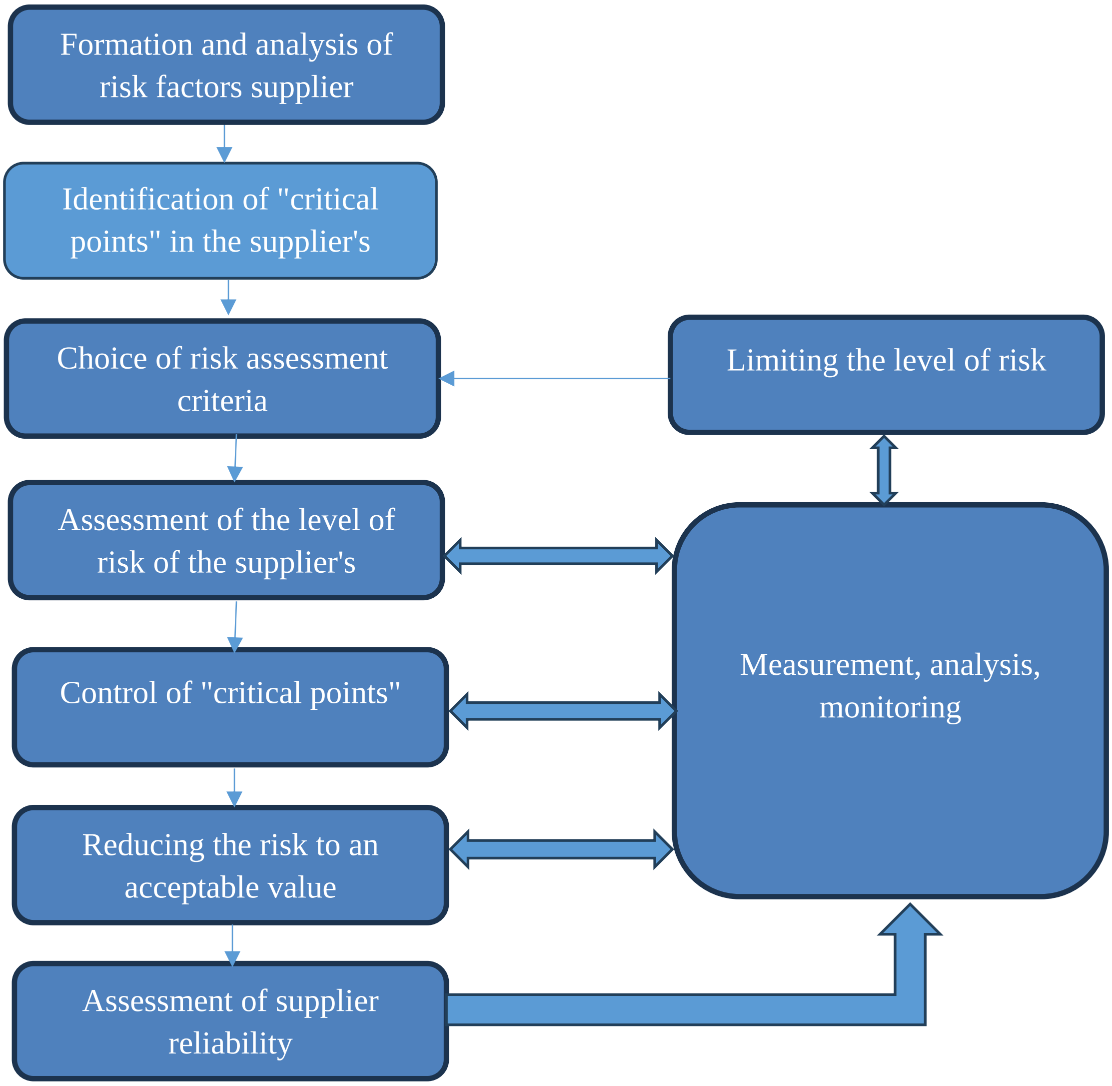


Fig. 1.3 Scheme of supplier reliability analysis

Source: compiled by the authors

Disruptions in the supply system are understood as random deviations from normal behavior. These deviations correspond to changes in process parameters and/or results of interaction of supply chain elements. Violations, as a result of exposure to dangerous factors, can be mutually compensated. Thus, the impact of disruptions on supply chain interactions is always manifested through the reliability of suppliers. The diagram of supplier reliability analysis is shown in Fig. 1.3.

In this sense, reliability can be defined as the resistance of economic objects to various influences and errors of partners.For example, the reliability of material and technical supply is "the guarantee of providing the consumer with the material resources he needs during a given period of time, regardless of the possible occurrence of shortages, violations of delivery terms"[31].

However, today the emphasis in the design of supply chains should be on increasing the reliability of the entire chain as a whole. There are three main ways to achieve supply chain reliability, which can be roughly divided into: quantitative, qualitative and combined approaches.

Quantitative approach – introduction of reserve elements of the supply chain. For example, inviting additional carriers that will carry out uninterrupted transportation of goods in the event that the main carrier is unable to fulfill its contractual obligations for one reason or another.

Qualitative approach – increasing the reliability of all elements of the supply chain (or the most unreliable of them), for example, reducing the time of cargo delivery and, as a result, increasing the accuracy of its delivery or organizing special methods of its transportation to increase the preservation of cargo.

A combined approach – application of the first two approaches in aggregate.

The calculation of reliability indicators is solved using the methods of probability theory, risk theory, set theory, etc.

In the most general form, the reliability of supply processes is calculated as follows:

[31]Carvalho N., Naghshineh V., Govindan K., Cruz-Machado V. The resilience of on-time delivery to capacity and material shortages: An empirical investigation in the automotive supply chain, Computers & Industrial Engineering, Volume 171, 2022, 108375.

$$P = 1 - Liquid, \tag{1.3}$$

where: P – reliability of supply;

Liquid – the probability of refusal to satisfy the supply request or the probability of refusal by the i-th supplier.

When interacting with several suppliers, formula (1.3) takes the following form:

$$P = 1 - \prod_{i=1}^{n}(1 - P_i), \tag{1.4}$$

where: Pi is the reliability of the i-th supplier.

Therefore, in our study, reliability of supply considers a set of criteria such as the efficiency of order fulfillment from the point of view of compliance with delivery terms, the quality of services provided, the range of products and total costs.

Disruptions in the supply system are understood as random deviations from normal behavior. These deviations correspond to changes in process parameters and/or results of interaction of supply chain elements.

Violations as a result of exposure to dangerous factors that can be mutually compensated ("add up"). Thus, the impact of disruptions on interactions in the chain is always manifested through the reliability of suppliers.

In connection with the acceleration of the pace of changes in the transport market, there are new, increased requirements for the reliability of supplies, which are met by indicators of reliability, flexibility and response time (reactivity) of the supplier to market changes. To satisfy them, a more efficient use of resources based on automatic identification technologies is necessary[32]. In order to increase the efficiency and quality of the supplier's services, it is necessary to shorten

[32]Emmens T., Amrit S., Abdi A., Ghosh M. The promises and perils of Automatic Identification System data, Expert Systems with Applications, Volume 178, 2021, 114975.:Charles V., Emrouznejad A. Gherman T. A critical analysis of the integration of blockchain and artificial intelligence for supply chain. Ann Oper Res 327, 7–47. 2023.https://doi.org/10.1007/s10479-023-05169-w;Spieske A., Birkel, H. Improving supply chain resilience through industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic. Computers & Industrial Engineering, 158, 2021. 107452

delivery times and increase reactivity, i.e. shorten the response time to consumer requests.

Fast implementation of delivery stages requires new organizational and technological measures. They are aimed at maintaining a high level of pre-sales preparation, shortening the life cycle, procurement and delivery times, and reducing resource stocks.

At the same time, it should be noted that the attractiveness of the supply chain for the client is determined by a certain level of reliability, which should have competitive advantages over the reliability of similar supply chains of other companies present on the goods (services) market.

The high-quality functioning of the supply chain according to the given reliability criterion depends on condition 1.5:

$$Ps \geq P0, \qquad (1.5)$$

where: Ps is the reliability level of the entire supply chain;

P0 is the required level of reliability.

Reliability in this case means the probability of performing the required functions in a certain time interval.

Product supply management, taking into account the assessment of the reliability and risk of the supplier, should be carried out within the framework of an integrated approach, where the state of the process is characterized by the values of two parameters:

– profitability (degree of expenses) (Di);

– the probability of receiving income for the use of an effective structure of processes (Pj).

To determine the risk of distribution (supply) of material resources through different suppliers, it is advisable to determine the mean square deviation, which can serve as an indicator of how much each option differs from the average value. This indicator can characterize the absolute risk according to the structure of resources and the expected income from their use:

$$R_i = \sqrt{\frac{\sum(D\text{п}_i + Dc_i)}{n}}^2, \quad (1.6)$$

where: Ri is the total average squared deviation for all elements of profitability, taking into account the probability;

$D\text{п}_i$ – optimized profitability of the i-th element of resources;

Dc_i – average profitability for the i-th element;

n is the number of elements.

The risk factor K will be determined by the ratio of the average squared (standard) deviation Ri to the average profitability of all elements Dci of the total income for the entire supply chain.

$$\text{К} = \frac{R_i}{Dc_i}, \quad (1.7)$$

The following groups of risk factors affect the security of supply chains[33]:

- physical: theft of property (loss); low quality of input raw materials and materials; vehicle accidents; accidents of main equipment, etc.;

- economic: inaccuracy and unreliability of forecasting demand for products; disruption of the supply of materials; supply of low-quality resources; lack of funds for the purchase of resources; rising prices for resources, etc.;

– technological: reducing the throughput (capacity) of a link of the logistics system or a counterparty of the supply chain; technical impossibility of production; equipment failure; violation of production, storage and transportation technology; physical wear and tear of production equipment, vehicles, warehouse lifting and transport equipment; non-compliance with the technology of production, storage, transportation, etc.;

[33]Vilko J., Hallikas J. Risk assessment in multimodal supply chains, International Journal of Production Economics, Volume 140, Issue 2, 2012, 586-595; Muhammad M. Jajja S., Chatha K., Farooq S. Supply chain risk management and operational performance: The enabling role of supply chain integration, International Journal of Production Economics, Volume 227, 2020, 107667.

– organizational: inefficiency of sales activities; lack of quality control and supply chain monitoring system; errors in the selection of intermediaries; inefficient inventory management, etc.

And the management of the reliability of the supply chain is connected with the choice of one or another tool (a method of increasing its reliability), which allows in specific conditions or for a specific business process to achieve the set goal.

Summarizing the above, it should be noted that despite the development of logistics and supply chain management worldwide, many of the theoretical and practical problems in the reliability of supply chains remain unsolved. In our opinion, these include the problems of developing a classification of assessment methods and models and ensuring the reliability of operations in supply chains, as well as the problems of developing planning models for individual business processes in supply chains under conditions of uncertainty and risk. Although the issue of the reliability of supply chains began to be raised in the works of domestic and foreign authors relatively recently, there are already many approaches, methods and models for improving the reliability of supply chains. Therefore, in our opinion, it is advisable to conduct a critical analysis of these approaches, methods and models, as well as to give their classification.

1.2 Factors influencing supply chain reliability and approaches to its assessment

Due to the existence of a sufficiently large number of influencing factors, the processes taking place in the supply chain are prone to randomness and variability, which directly affects the reliability of the entire supply system.

Studying the operation of supply chains scientists[34] distinguish four main groups of factors affecting the reliability of the supply chain:

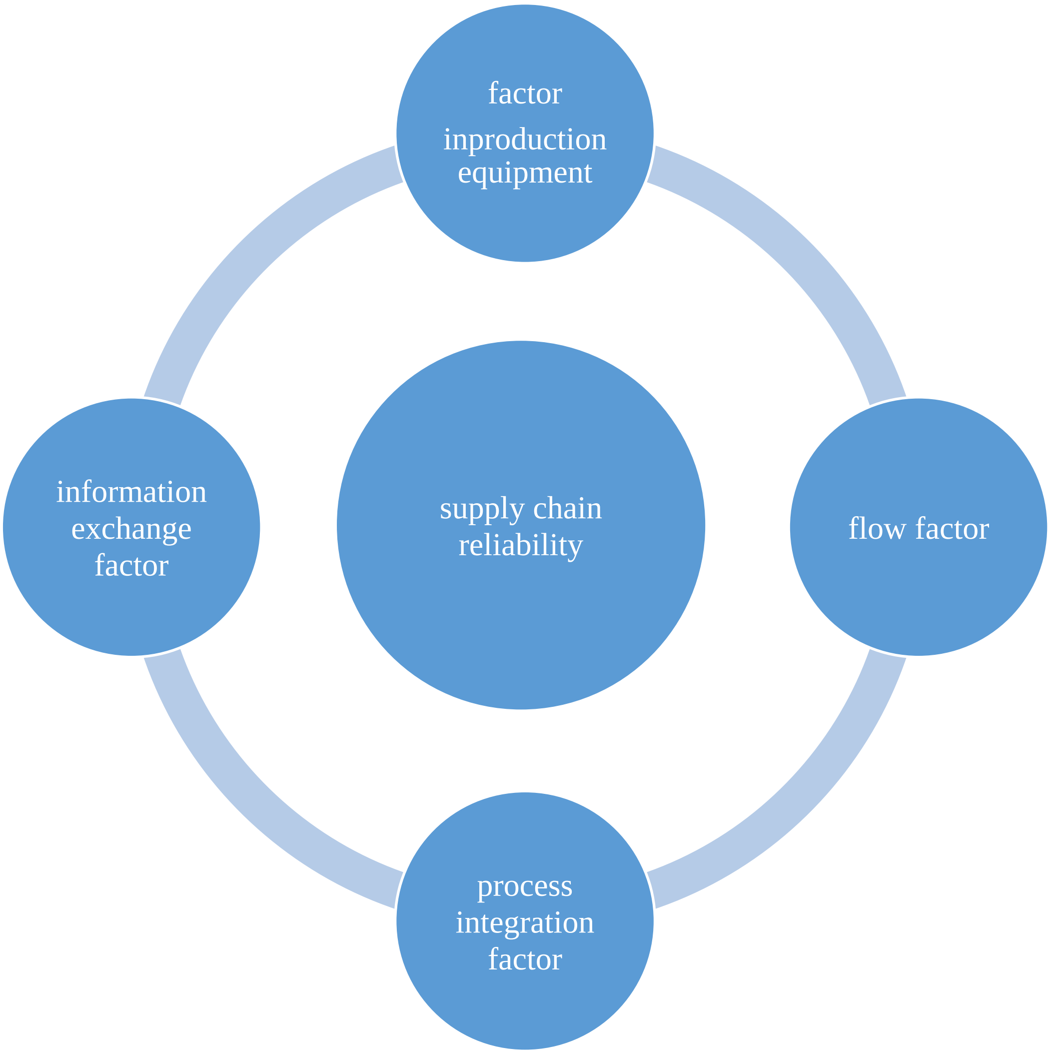


Fig. 1.4 Factors affecting supply chain reliability

Source: compiled by the authors

[34]Ahmed HF, Hosseinian-Far A., Khandan R., Sarwar D., E-Fatima K. Knowledge Sharing in the Supply Chain Networks: A Perspective of Supply Chain Complexity Drivers. Logistics 2022, 6, 66.https://doi.org/10.3390/logistics6030066;Ab Talib MS,Abdul Hamid AB,Thoo ACCritical success factors of supply chain management: a literature survey and Pareto analysis,EuroMed Journal of Business, 2015, Vol. 10 No. 2, 234-263.https://doi.org/10.1108/EMJB-09-2014-0028.;Jiang P., Wang Y., Liu C., Hu Y.-C., Xie J. Evaluating Critical Factors Influencing the Reliability of Emergency Logistics Systems Using Multiple-Attribute Decision Making. Symmetry 2020,*12*, 1115. https://doi.org/10.3390/sym12071115.;Kumar D.,Sony G.,Kazancoglu Y.,Rathore APSOn the nature of supply chain reliability: models, solution approaches and agenda for future research,International Journal of Quality & Reliability Management, 2023, Vol. ahead-of-print No. ahead-of-print.https://doi.org/10.1108/IJQRM-08-2022-0256;Zhang M., Chen J., Chang S.-H. An adaptive simulation analysis of reliability model for the system of supply chain based on partial differential equations, Alexandria Engineering Journal, Volume 59, Issue 4, 2020, 2401-2407.

1. The factor of production equipment (the factor of the cooperation contract; the factor of joint work; the factor of the information platform).

Each company in the supply chain has its own internal cycle with its supply, production and sales links. Since the state of equipment failure is random, in the event of a failure of the production equipment of a certain process on the production line, if the existing safety stock is exhausted during the repair time, then the production of finished products will stop, and the amount of raw material stocks before this process will gradually increase to such an extent that it will be impossible save.

Accordingly, other processes down and up the supply chain must stop. For this reason, the equipment factor is one of the important factors that affect the reliability of production units of enterprises.

2. Flow factor.

The three main flows in a supply chain system are the flows of materials, capital and information. The quality, quantity, and accuracy of material delivery times affect the efficiency of the overall supply chain system. If the incoming material flows (raw materials, semi-finished products, component materials, etc.) are of inadequate quality, the output flow (finished products, semi-finished products) will also be of inadequate quality, which means that the reliability of the supply chain system is low. As a result of a shortage, an uneven amount of materials will lead to a failure in the supply of the same batch of products, because it cannot meet the customer's needs. Likewise, late delivery directly affects supply chain relationships and customer loyalty, and can cause serious customer churn.

3. Process integration factor.

In order to effectively provide consumers with reliable products, informational, material and financial synergy is necessary between enterprises participating in the supply chain. The operation of the supply chain system in the process of cooperation is multi-level and multi-link. If the stability of demand and the efficiency of supply in the supply chain cannot be achieved, the demand for products will gradually increase from the supply side to the consumer side, and the so-called whip effect will appear (Fig. 1.5), which leads to an increase in the amplitude of demand fluctuations as information progresses along the supply chain, and the longer the logistics chain, the greater the amplitude of fluctuation and the higher the delivery time. When the whiplash effect occurs, the well-established movement of information and material flows of the logistics chain is disrupted, which causes a deviation from the main goal of the logistics system as such - to fulfill the client's order and satisfy both its own and the client's needs.

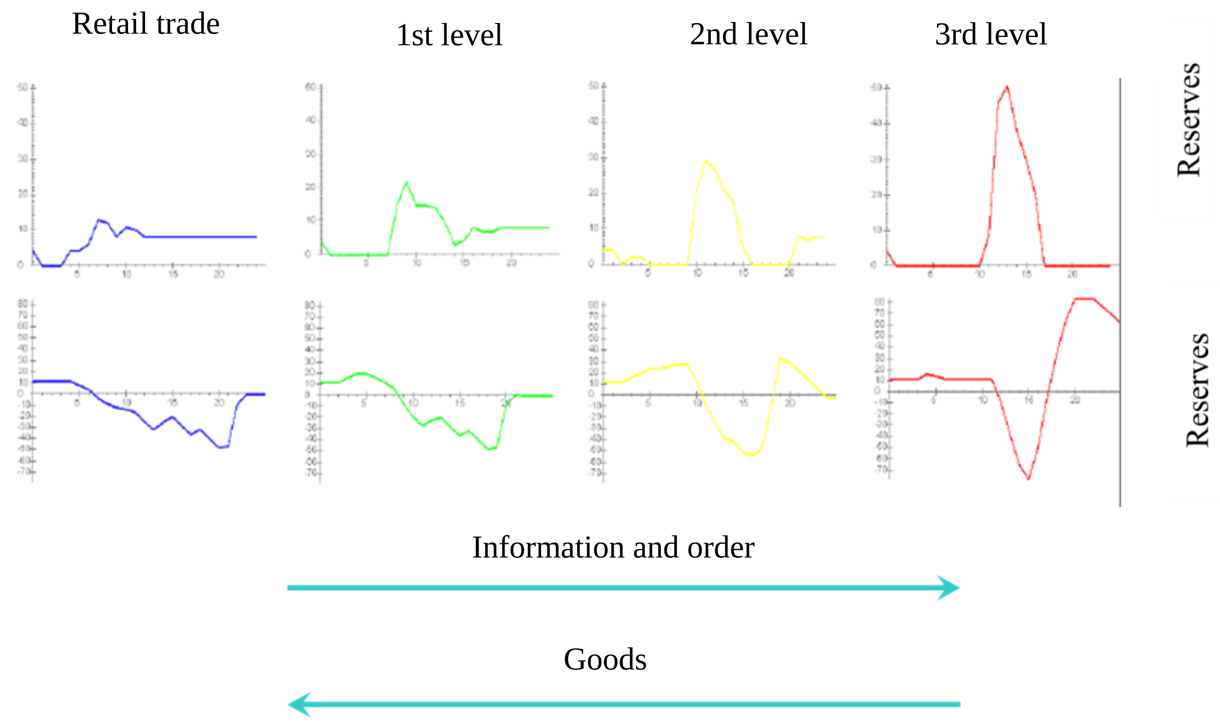


Fig. 1.5 Graphic representation of the whip effect.

Source: compiled by the authors

At the same time, the delay in the transfer of information about demand from the supply side to the consumption side also makes the supply chain less flexible and complicates its operation in a changing market environment.

4. Information exchange factor. When the exchange of information is asymmetric, there may be delays in adjusting production plans of supply chain

participants and corresponding temporary delays in deliveries. Eliminating the influence of this factor requires the creation of an end-to-end supply chain information system hosted on a cloud platform for real-time information exchange[35], so that each of the participants in the supply chain has the opportunity to respond in a timely manner to possible fluctuations in demand and make appropriate decisions regarding further supplies of their own products.

The network architecture of the information system is presented in fig. 1.6.

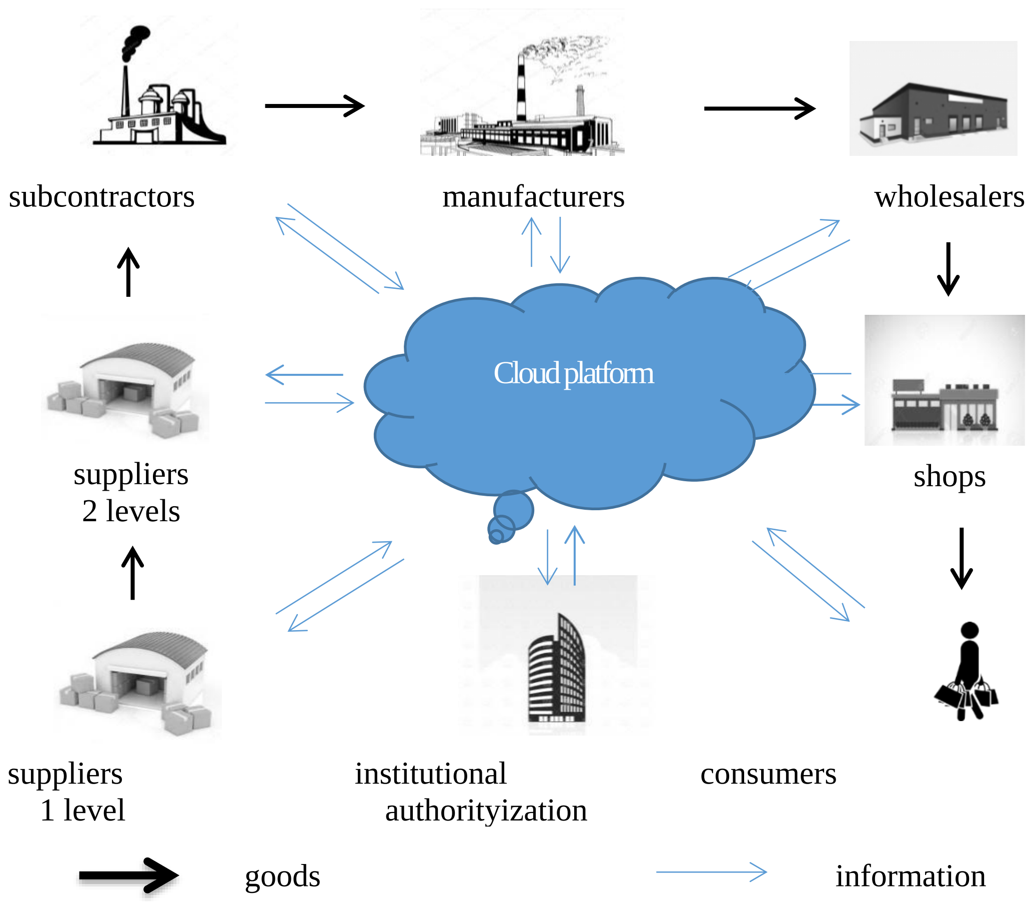


Fig. 1.6 Network architecture of the information system supply chain

Source: compiled by the authors

[35]Spieske A., Birkel, H. Improving supply chain resilience through industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic. Computers & Industrial Engineering, 158, 2021. 107452

It is obvious that due to the failure of the information system, the supply chain suffers losses (financial and reputational) from a decrease in the reliability of its work, or may even be unable to sell production products in the required quantity and on time. The interdependence of supply chain partners around the world causes the so-called butterfly effect, resulting in disruptions and negative effects[36] - "waves", "dominoes" or "snowballs", which spread to the efficiency of the entire supply chain and significantly affect its structural design and planning parameters[37].

The presence of effects and factors affecting the reliability of the supply chain require the application of certain approaches to their reduction or elimination in practical activities. Among them, the following became the most widespread:

1. The process approach and the SCOR model developed on its basis;

2 Creation of dynamic supply chains;

3. Evaluation of the quality of logistics service based on the "perfect order" indicator.

SCOR model (Supply Chain Operations Reference-model) is specially developed for managing supply chains. The prerequisites for its development and implementation were the need to create a methodology for modeling end-to-end management of supply chains and a common understanding of the processes underlying it and the evaluation of these processes. The creation of a standardized process model was initiated by the Supply Chain Council (SCC) in order to more effectively analyze, plan and design supply chains.

The SCOR model is a reference model of the supply chain that provides companies with the opportunity to communicate in the language of common standards, technologies, communications, rules and compare themselves with

[36]Belhadi A., Kamble S., Jabbour CJC, Gunasekaran A., Ndubisi NO, Venkatesh M. Manufacturing and service supply chain resilience to the COVID-19 outbreak: Lessons learned from the automobile and airline industries Technological Forecasting and Social Change, 163, 2021, Article 120447,10.1016/j.techfore.2020.120447

[37]Hosseini S., Ivanov D. A new resilience measure for supply networks with the ripple effect considerations: A Bayesian network approach Annals of Operations Research, 1–27 (2019), 10.1007/s10479-019-03350-8.

competitors, learn from business organizations in this industry and from companies in other industries[38]. The SCOR model belongs to the class of process-oriented models, in which the activity of the modeling object is considered as a set of "end-to-end" (cross-functional) processes (Fig. 1.7).

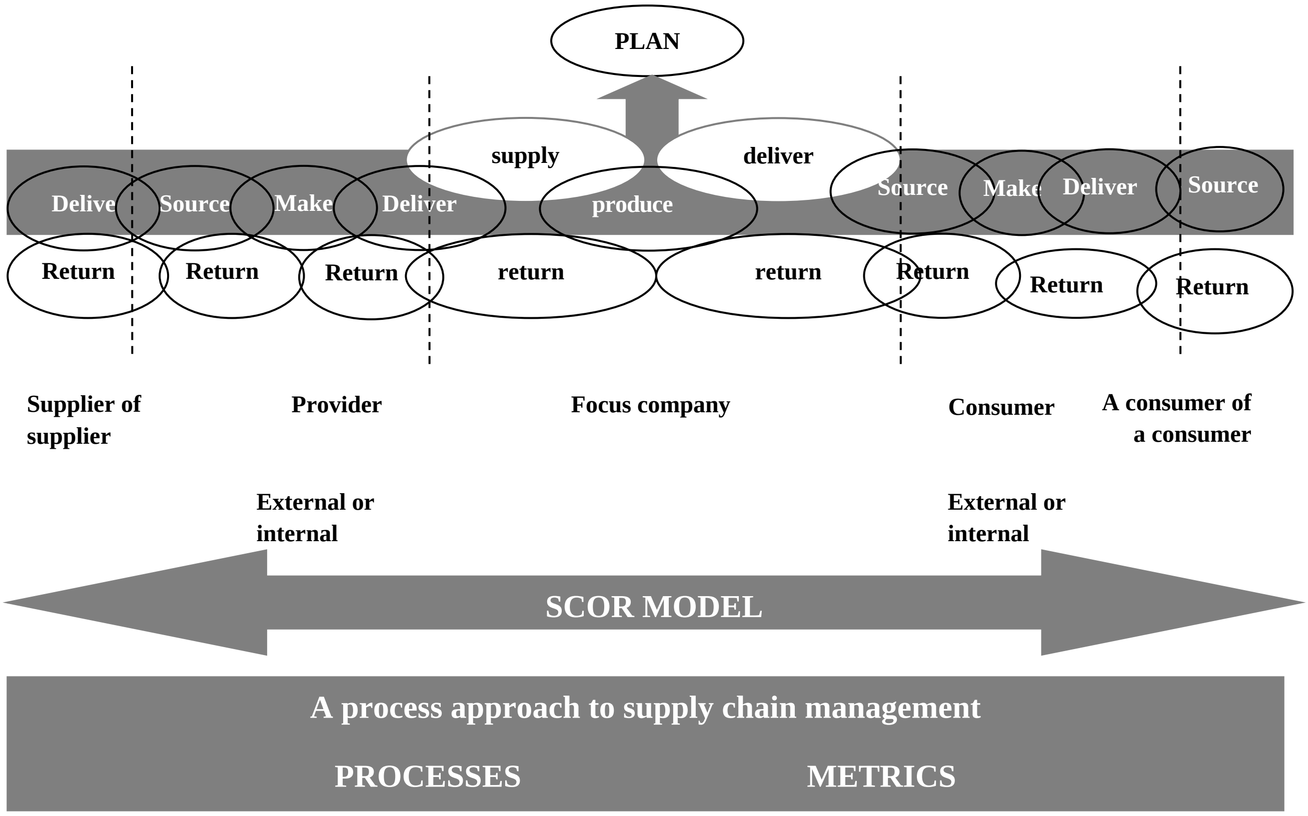


Fig. 1.7 Scheme of the efferent model of operations in supply chains.
Source: compiled by the authors

It uses a system of standard business processes based on global best practices, a system of key performance indicators (KPI) of supply chain business processes, and a list of employee skills and competencies aligned with the processes. The SCOR model describes both the interaction processes of supply chain participants and the internal processes of logistics systems of enterprises participating in the chain.

[38]Delipinar G., Kocaoglu V., Using SCOR Model to Gain Competitive Advantage: A Literature Review, Procedia - Social and Behavioral Sciences, Volume 229, 2016, 398-406.;Saen RF, Izadikhah, M.. A novel SCOR approach to assess the sustainability of supply chains. Operations Management Research.. 2022. https://doi.org/10.1007/s12063-022-00331-2

The model considers the following processes:

- planning;
- supply;
- production;
- delivery;
- return

The structure of the SCOR model covers three rather popular management concepts: benchmarking, use of best practices, and reengineering of business processes and contains four levels of process detailing (Figure 1.8).

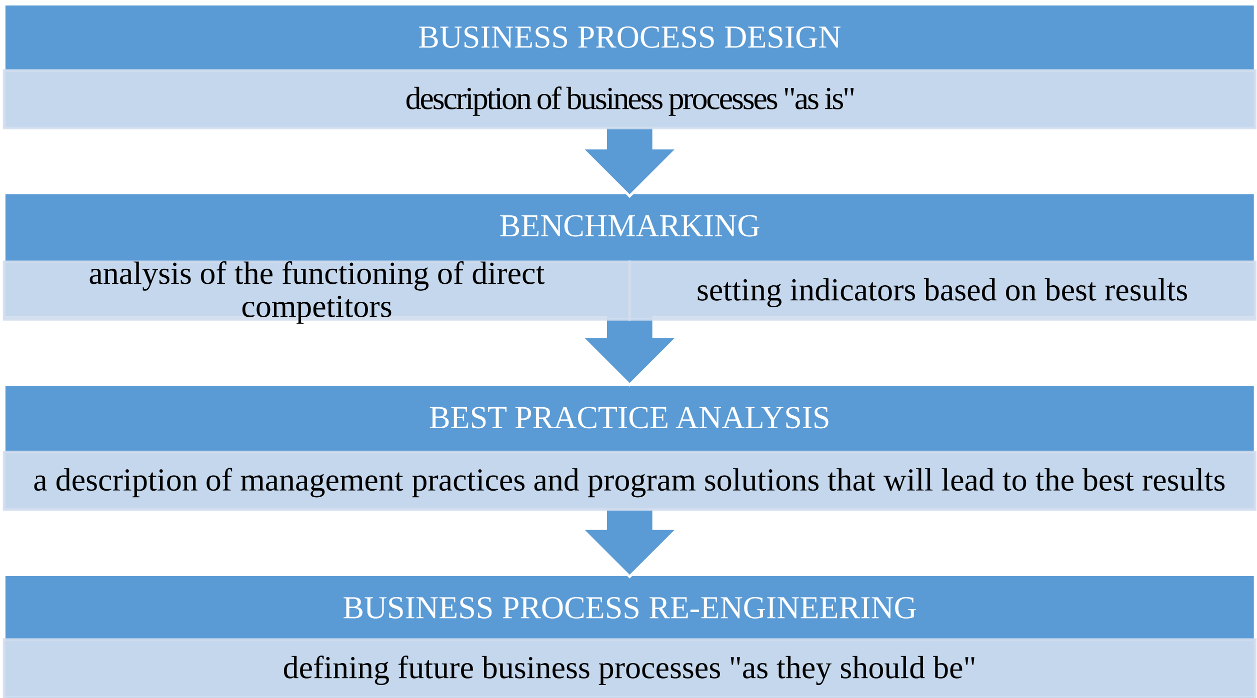


Fig. 1.8 SCOR model design stages

Source: compiled by the authors

First level – basic competitiveness. At this level, the company formulates competitive objectives and strategy for the supply chain. It includes six types of processes: planning, production, supply, delivery, return and support.

The second level – configuration. In accordance with the requirements of the strategy, taking into account the applied technologies, logistics principles and rules, the company designs the supply chain. This level includes indicators that help to diagnose the metrics of the first level in terms of the deviation of the planned values from the benchmarks included in the "benchmarking platform" (competitors, leaders).

The third level – efficiency, processes and practices, systems. The processes of each category are divided into elements, the combination of which will determine the competitiveness of the company. Here are the parameters and measures used to evaluate the performance of each element.

The fourth level – supply chain processes and implementation. At this level, elements of processes are divided into components of their work and operations.

In the SCOR model, the efficiency of the supply chain is determined based on the assessment of indicators that characterize such parameters of functioning as reliability, speed of response, flexibility, costs and efficiency of asset management of the supply chain. Performance indicators are divided according to the level of the SCOR model. First-level performance indicators, which are high-ranking measures that can summarize a number of SCOR-model processes, are presented in Table 1.2.

Table 1.2 – Supply chain performance parameters and first-level indicators.

Functioning parameters	Definition of parameters	Indicators of the first level
Supply chain reliability	Functioning of the supply chain precisely in the part of supplies: logistic mix-7R	Fulfillment of supplies
		Demand saturation norms
		Share of error-free ("perfect") orders

Supply chain feedback	The speed at which the supply chain delivers the product to the end consumer	Order fulfillment time
Supply chain flexibility	The rate at which the supply chain responds to changes in the market situation in order to obtain or maintain competitive advantages	Response time
		Production flexibility
Supply chain costs	Costs associated with operations in supply chains	Cost of goods sold
		Total costs of the chain
		Productivity with added value
		Costs for product return or disposal
Effectiveness of asset management in the supply chain	Effectiveness of the asset management organization. Includes management of all assets: working capital and fixed assets	Cash flow cycle
		Inventory volume in days of sale
		Asset turnover

Source: compiled by the authors

The effectiveness of the operational strategy of the supply chain at the second and third levels is evaluated on the basis of KPIs, which each company develops independently, based on the existing business structure and specific business processes. The limitation of the SCOR model for the purpose of assessing the reliability of the supply chain, in our opinion, is that, firstly, this model interprets the concept of reliability of the supply chain in a limited way.

Reliability, in this case, means compliance with qualitative, quantitative and time parameters during orders, that is, reliability is not considered from the standpoint of the failure of the supply chain and the costs of maintaining its efficiency.

Reliability in the SCOR model is defined as the ability to perform tasks as expected by consumers. This requires the ability to forecast demand for products, changes in internal and external factors affecting the processes associated with the movement of goods and material values, and to achieve results in accordance with the logistics principles of delivery:

– the right product (right / required product);

– in the specified quantity (right quantity);

– required quality (right quality on customers);

– at the right price or with the minimum level of costs (right price / cost);

– at the right time (right time);

– in the right place (right place);

– to the right customer (right customer);

– in the required condition and packaging (right condition), which causes as little damage to the environment as possible (right way);

– with correctly executed documents (right information);

– from the right supplier.

The first six items in the above list make up the "6-Rs" of logistics. And together with the seventh item we get "7-Rs". Here, "required quality" coincides in content with the next item - "required state", since both the first and the second relate, first of all, to products. But, adding the eighth item, taking into account the requirements for the process of moving commodity values, we have "8-Rs". The development of the concept of supply chain management led to the consideration of two more principles formulated in the last two points.

To assess reliability, first of all, they track how many deliveries and/or orders from consumers are completed without violations (on time and to the specified place).

Table 1.3 – Attributes and indicators in the SCOR model

Attribute	Indicator / metric
Reliability	– Perfect Order Fulfillment (RL.1.1) – % of orders delivered in full (% of Orders Delivered In Full – RL.2.1) – Correctness of goods delivery (Delivery Item Accuracy – RL.3.33)
Responsiveness	– Order Fulfillment Cycle Time (RS.1.1) – Procurement cycle (Source Cycle Time – RS.2.1) – Identify sources of supply cycle time (Identify Sources of Supply Cycle Time – RL.3.35) – Manufacturing cycle (Make Cycle Time – RS.2.2)
Agility	– Upside Supply Chain Flexibility – AG.1.1 – Adaptability when demand increases – the maximum volume of production during the required period of time (Upside Supply Chain Adaptability – AG.1.2) - Adaptability in the event of a drop in demand - the amount of production reduction during the required period of time without additional costs due to the increase in stocks, downtime, fines (Downside Supply Chain Adaptability - AG.1.3) – Overall value of assets exposed to risk (Overall Value At Risk – AG.1.4)
Cost / expenses (Cost)	Total cost to serve (Total Cost to Serve – CO.1.001)
Assets	– Cash-to-Cash Cycle Time (AM.1.1) – Return on Supply Chain Fixed Assets – AM.1.2 – Return on Working Capital – AM.1.3

Source: compiled by the authors based on Jamehshooran BG, Shaharoun M., Awaluddin & Habibah H. Assessing supply chain performance through applying the SCOR model. 2015. 4. 1-11.; van Engelenhoven T., Kassahun A., Tekinerdogan B. Systematic Analysis of the Supply Chain Operations Reference Model for Supporting Circular Economy. Circ. Econ. Sust. 3, 811-834 (2023). https://doi.org/10.1007/s43615-022-00221-6.

According to the key indicators responsible for reliability in the SCOR model, the indicators of the RL.1 group include: Perfect Order Fulfillment (RL.1.1), % of Orders Delivered In Full (RL. 2.1), correctness of delivery of goods (Delivery Item Accuracy - RL.3.33) (see table 1.3).

The evaluation of the efficiency of the supply chain and, in particular, its reliability, is carried out by comparing the indicators achieved by the company with the indicators of the leading companies in this field of business. Obviously, such a comparison does not always allow for a correct assessment of both the efficiency and reliability of one's own supply chain. For example, if the share of error-free or "perfectly" fulfilled orders in the best companies is 97%, and in the analyzed company – 95%, this does not mean that the reliability of deliveries in the company under consideration is lower than in the best companies. In different companies, both product parameters and customer requirements for the supply of products of the same purpose may differ. These parameters and requirements may differ for divisions of the same company, but which operate in different markets or in different regions. Therefore, direct comparisons of companies based on indicators such as the share of error-free (perfect) orders or order fulfillment time are not always justified.

The SCOR model is a descriptive model, it allows you to describe the existing business processes of the supply chain ("as is"), to develop improved business processes ("as it should be"), to evaluate the company's functioning compared to the best results, and to develop such management tools, that will lead to the best results. But since the model is qualitative (descriptive), supply chain reengineering does not guarantee that business processes will be optimal, and the efficiency and reliability of the supply chain will be the highest.

Thus, the SCOR model was developed to more effectively analyze, plan and design supply chains. Its advantages are: standardization; inclusion of all types of "consumer-supplier" interaction and all stages of the material flow; interaction with the market; application of reverse logistics. The shortcomings of the SCOR model are considered to be that it: is unable to cover the entire value chain; does not include sales, marketing, research and development; focused on individual companies and not on the entire supply chain; limited to the modeling of planning and organization processes (lack of control and change stages).

*Creation of dynamic supply chains*is also one of the three main approaches to ensuring their reliability. Agility means being able to respond quickly on a global scale to the ever-changing demands of markets. Dynamism is characteristic of all business. It includes organizational structures, information systems, logistics processes and the level of professional competences of the staff. The key characteristic of a dynamic organization is flexibility. According to her, two alternative strategies are considered in supply chain management: "thrifty" and dynamic. The main characteristics of both strategies are compared with each other in Table 1.5.

Table 1.5 – Characteristics of "thrifty" and dynamic strategy

Factors, which influence the choice of strategy	Supply chain strategy	
	"thrifty"	"dynamic"
Basic orientation	Productivity	Efficiency
Product characteristics	Standard	Wide variety
Product life cycle	Long	Short

What is the emphasis on?	Economies of scale	Speed, flexibility and quality
Capacity utilization	The level is set by the graph production	The level is set by demand
Supplier selection criteria	Price and quality	Availability of reserve power.Speed, flexibility and quality

Source: compiled by the authors based on literary sources

An analysis of the factors affecting the overall choice of supply chain strategy shows that the "thrifty" option is fully justified in conditions where demand is predictable, requirements for variety are limited, and production volume is high.

Lean supply chains are formed in markets that focus on standard products. The most important processes for this category of supply chain are the management of production flows and logistics processes and the management of relationships with suppliers and the procurement process. These supply chains exist in companies such as VW, Renault and Hyundai.

A dynamic option, on the contrary, is necessary in a less predictable environment, when demand changes dramatically, and the requirements for product variety are high. Dynamic (customer-oriented) supply chains are formed in new markets and focused on relatively innovative products. The most important processes for this category of supply chains are customer service, relationship management and product development. These supply chains exist in companies such as BMW and Audi.

The concepts of "thrifty" and "dynamic" strategy are not mutually exclusive.Ideally, organizations should strive to create hybrid supply chain strategies that combine both of these philosophies, thereby achieving the most cost-effective solutions.

The choice of one or another variant of the hybrid strategy is based on: the application of the Pareto rule (80:20) to divide products into slow and fast-moving products.

A major problem encountered in most supply chains is limited “visibility” of actual demand. Because supply chains are often long and have multiple levels of inventory between the point of production and the end consumer, they typically operate based on forecasts rather than actual demand. The point at which the actual demand appears in the upper part of the supply chain is called the decoupling point or the order penetration point.

As a general rule, managers tend to use the strategy of moving the point of origin of the order down the supply chain, which has several advantages.

First, inventories can be held in the form of generic products, that is, standard semi-finished products awaiting final processing, and therefore reducing the number of product variants helps to reduce the volume of inventories in general.

Second, because the inventory here is typical in its physical nature, the flexibility of working with it increases, since the same components, modules or platforms can be used in different products.

Third, it is easier to make forecasts at the typical level than only at the level of finished products.

From the point of view of the expediency of using a hybrid strategy, the point of appearance of the order divides the supply chain into two parts: before the point of appearance of the order, it is advisable to use "thrifty" strategies, and after it - dynamic strategies (Fig. 1.9).

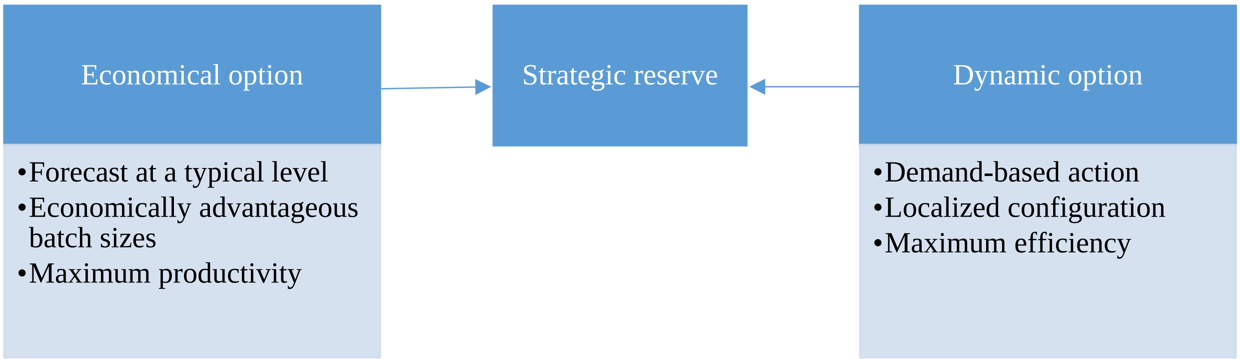


Fig. 1.9 Influence of the point of order appearance on the hybrid strategy selection procedure

Source: compiled by the authors

The choice of a hybrid strategy is also influenced by the division of demand into basic and wave components. Baseline demand can be met through classic "lean" procedures, allowing economies of scale to be achieved, while wave demand is met through more flexible and possibly more expensive processes (such as the use of contract manufacturing and logistics service providers). Thus, the methods described above allow you to choose the optimal hybrid supply chain strategy depending on the relevant business conditions (table 1.6).

Table 1.6 – Choosing a hybrid supply chain strategy

The method of choosing a hybrid strategy	elevant market conditions and operating environment
Pareto / 80:20 The use of "thrifty" methods for the production of products in large volumes, dynamic methods for products that are sold slowly.	High level of diversity; demand for the entire assortment does not change significantly
Point of order appearance The task: to act with the help of the "thrifty" option up to the point of	Possibility of modular production or creation of stocks of intermediate products; postponing the creation of

appearance and the dynamic option after it	the final configuration or distribution
Division of demand into wave and base components Management of the demand component with a high degree of predictability (basic) based on "thrifty" principles; using dynamic principles to work with a less predictable (wave) component	Where the base level of demand can be reliably predicted based on past experience and where there is local production and capacity for small batch production

Source: compiled by the authors based on literary sources

It should be noted that, firstly, the market conditions and operating environment presented in Table 1.6 influence the choice of dynamic production rather than dynamic logistics. Secondly, the use of a dynamic strategy does not exclude the use of a "thrifty" strategy. Moreover, the dynamic supply chain should have a number of special characteristics:

1) sensitivity to the market - the ability of the supply chain to determine real demand and respond to it;

2) virtuality – the use of information technologies for data exchange between buyers and suppliers;

3) coordination of processes – joint work of customers (buyers) with suppliers, joint development of products, use of common systems and information exchange;

4) network approach - the idea according to which the supply chain is a collection of partners connected to each other in the form of a network.

Analysis of the problem of creating dynamic supply chains allows us to conclude that, of course, achieving dynamism within the entire supply chain provides companies with a global competitive advantage by reducing order fulfillment cycle time, reducing equipment setup time, using modular production, and reducing inventories. But still, the creation of a dynamic supply chain allows you to achieve, first of all, an increase in efficiency, not reliability. Thus, creating a dynamic supply chain is a challenge that goes far beyond the scope of a single study.

The third widespread approach to assessing and ensuring the reliability of supply chains is to assess the quality of logistics service based on the Perfect Order Fulfillment (POF) indicator.

POF generally means the error-free execution of all operations of the complete order cycle in strict accordance with the contractual conditions. The number of operations is related to the specifics of orders and may vary. At least in foreign publications[39] accounting cases from 3 to 11 operations (or factors) taken into account for the POF level are described. In practice, the three-component POF model is most often used, which is determined by such factors as the timeliness of delivery, completeness of the order and error-free execution[40].

Timeliness means delivery on time, exactly within the term agreed with the customer (delivery on time).

Under completeness – delivery of a fully completed order in full (delivery in full).

[39]Ayan, B.; Guner, E.; Son-Turan, S. Blockchain Technology and Sustainability in Supply Chains and a Closer Look at Different Industries: A Mixed Method Approach. Logistics 2022, 6, 85.https://doi.org/10.3390/logistics6040085; Dutta P, Choi TM, Somani S, Butala R. Blockchain technology in supply chain operations: Applications, challenges and research opportunities. Transp Res E Logist Transp Rev 2020 Oct;142:102067.doi: 10.1016/j.tre.2020.102067.; Hübner A., Holzapfel A., Kuhn, H. Distribution systems in omni-channel retailing. 2016. Bus Res 9, 255–296.https://doi.org/10.1007/s40685-016-0034-7;Mohsen B. Impact of Artificial Intelligence on Supply Chain Management Performance. Journal of Service Science and Management, 2023, 16, 44-58. doi:10.4236/jssm.2023.161004.; Serhat Karakutuk S., Arslan Ornek M.A goal programming approach to lean production system implementation. Journal of the Operational Research Society 2023, 74:1, pages 403-416.; Peeters K., van Ooijen H. Hybrid make-to-stock and make-to-order systems: a taxonomic review, International Journal of Production Research, 2020, 58:15, 4659-4688, DOI:10.1080/00207543.2020.1778204

[40]Rita R., Oliveira T., Farisa A. The impact of e-service quality and customer satisfaction on customer behavior in online shopping, Heliyon, Volume 5, Issue 10, 2019, e0269; Raja Santh, A. Muthuswamy P. Influence of Blockchain Technology in Manufacturing Supply Chain and Logistics. Logistics 2022, 6, 15. https://doi.org/10.3390/logistics6010015

Error-free means the delivery of the ordered goods without damage (correct condition and correct place) in compliance with the conditions of transportation and the absence of errors in the documents[41]. In general, nowadays, infallibility is associated with the absence of losses for the consumer in one form or another[42].

POF is considered as a reliability characteristic of the SCOR model and a tool for synchronizing supply channels of the logistics chain. We should also note that a number of publications note the difficulty of determining POF in practice[43]. At the same time, it is emphasized that a real increase in the level of POF by 3% provides an increase in the company's profit by 1%[44], and companies that provide practical implementation of POF significantly increase competitiveness[45].

However, there is currently no unambiguous formal method of POF assessment. As a rule, this is the business of the supply management department of the company that provides logistics services. Neither the list nor the number of factors affecting the POF assessment has been discussed either in the scientific literature or at the practical level. The three factors mentioned above are most often considered. However, there are examples of using five, eight and even eleven indicators. In some cases, instead of POF, the Perfect Order Index (POI) is used, which is determined by the product of the probabilities of error-free execution of the order by seven or four factors. At the same time, it is noted that

[41]Tao L., Liu S., Xie N., Javed SA Optimal position of supply chain delivery window with risk-averse suppliers: A CVaR optimization approach, International Journal of Production Economics, Volume 232, 2021, 107989

[42]Hammami R., Frein Y., Albana AS Delivery time quotation and pricing in two-stage supply chains: Centralized decision-making with global and local managerial approaches, European Journal of Operational Research, Volume 286, Issue 1, 2020, 164-177 ; Sorooshian S., Khademi Sharifabad S., Parsaee M., Afshari AR Toward a Modern Last-Mile Delivery: Consequences and Obstacles of Intelligent Technology. Appl. Syst. Innov. 2022, 5, 82. https://doi.org/10.3390/asi5040082

[43]Asha A.A., Dulal M., Ahashan Habib Dr. The influence of sustainable supply chain management, technology orientation, and organizational culture on the delivery product quality-customer satisfaction nexus, Cleaner Logistics and Supply Chain, Volume 7, 2023, 100107; Dethlefs S., Ostermeier M., Hübner A. Rapid fulfillment of online orders in omnichannel grocery retailing, EURO Journal on Transportation and Logistics, Volume 11, 2022, 100082; Raj A., Mukherjee AA, de Sousa Jabbour ABL, Srivastava SK Supply chain management during and post-COVID-19 pandemic: Mitigation strategies and practical lessons learned. J Bus Res. 2022 Mar;142:1125-1139. doi: 10.1016/j.jbusres.2022.01.037.

[44] Deng L., Xu W., Luo J. Optimal Loan Pricing for Agricultural Supply Chains from a Green Credit Perspective. Sustainability 2021, 13, 12365.https://doi.org/10.3390/su132212365.

[45] Dixit S.,Singh S.,Dhir S.,Dhir S. Antecedents of strategic thinking and its impact on competitive advantage,Journal of Indian Business Research, 2021, Vol. 13 No. 4, 437-458.https://doi.org/10.1108/JIBR-08-2020-0262

in practice the number of factors is set by the company providing the supplies[46]. A significant problem is the calculation of the POF itself. POF is usually expressed as the probability of an order being executed without error[47], which is determined by the product of the probabilities of error-free execution of basic operations:

$$P_o = \prod_{i=1}^{n} P_i \tag{1.8}$$

where: n is the number of operations in a perfect order,

Pi is the probability of error-free execution of the ith operation.

Such a model has certain disadvantages, because its essence lies in the assumption of independence of operations and unlimited time of contractual agreements between consumers and suppliers. However, errors at the stage of receiving and processing the order can lead to errors in the assembly and documentation. Delays in the execution of operations in the warehouse and errors in the planning of the shipment of goods can cause a violation of delivery terms. In this regard, this model should use conditional probabilities of events, which are determined under the condition of error-free execution of combined operations.

Another important problem of POF estimation is related to the limited terms of contractual agreements between suppliers and consumers, which, in turn, leads to the uncertainty of the concept of "probability" of the POF model. There are three approaches to defining the concept of "probability"[48]:

– classical, based on counting the number of positive results of experiments and its relation to equally possible results (classical formula for the probability of an event);

– frequent (statistical), based on the concept of the frequency of the event in this series of experiments;

[46]Kaur H., Singh SP Multi-stage hybrid model for supplier selection and order allocation considering disruption risks and disruptive technologies, International Journal of Production Economics, Volume 231, 2021, 107830

[47]Zeng Z., Chen Y., Zio E., Kang R. A compositional method to model dependent failure behavior based on PoF models, Chinese Journal of Aeronautics, Volume 30, Issue 5, 2017, 1729-1739

[48]Zeng Z., Kang R., Chen Y., Using PoF models to predict system reliability considering failure collaboration, Chinese Journal of Aeronautics, Volume 29, Issue 5, 2016, 1294-1301

– set-theoretic, based on set theory.

As for the methods of assessing the reliability of the supply chain, scientists also divide them into three groups.

The first group is based on the ability of the supply chain to quickly and efficiently recover from a disruption to a normal or even desirable state[49].

In the second group, reliability refers to the ability of the supply chain to adapt to catastrophic events and recover from them[50].

In the third, it describes reliability as the ability of the supply chain to be prepared for potential failures, to be able to reduce the impact of these events once they occur, and to minimize the time needed to restore to a standard state[51].

The methodology for planning the activities of supply chain participants to ensure their reliability also includes a number of groups of key parameters, namely:

The first group includes:

1) Fault-free normal functioning, which means the preservation of quantitative and qualitative characteristics of the logistics activity of the chain as a whole[52];

2) The specified operating conditions, which are understood as a system of restrictions in changing the reliability of the logistics system[53].

---

[49]Behzadi G., O'Sullivan MJ, Olsen TL On metrics for supply chain resilience European Journal of Operational Research, 287 (1) (2020), 145-158.;Novak DC, Wu Z., Dooley KJ Whose resilience matters? Addressing issues of scale in supply chain resilience Journal of Business Logistics, 42 (3) (2021), pp. 323-335.

[50]Hosseini S., Ivanov D. Dolgui A. Review of quantitative methods for supply chain resilience analysis Transportation Research Part E: Logistics and Transportation Review, 125 (2019), 285-307.; Kaur H., Singh SP Disaster resilient proactive and reactive procurement models for humanitarian supply chain Production Planning & Control, 33 (6–7) (2022), 576-589.

[51]Akkermans H., van Wassenhove LN Supply chain tsunamis: Research on low-probability, high-impact disruptions Journal of Supply Chain Management, 54 (1) (2018), 64-76.; Golan MS, Jernegan LH, Linkov I. Trends and applications of resilience analytics in supply chain modeling: Systematic literature review in the context of the COVID-19 pandemic Environment Systems and Decisions, 40 (2020), 222-243.

[52]Li Y., Zobel CW, Seref O., Chatfield D. Network characteristics and supply chain resilience under conditions of risk propagation, International Journal of Production Economics, Volume 223, 2020, 107529.

[53] Kumar D.,Sony G.,Kazancoglu Y., Rathore APSOn the nature of supply chain reliability: models, solution approaches and agenda for future research",International Journal of Quality & Reliability Management, 2023. Vol. ahead-of-print No. ahead-of-print.https://doi.org/10.1108/IJQRM-08-2022-0256; AL-Shboul M.A., An investigation of transportation logistics strategy on manufacturing supply chain responsiveness in developing countries: the mediating role of delivery reliability and delivery speed, Heliyon, Volume 8, Issue 11, 2022, e11283.

To the second:

1) Reliability of the logistics system – the reliability coefficient, which takes into account the travel time of the vehicle and the delay time of receiving the request for transportation at the logistics center, the delay time at the transport company[54];

2) Reliability of elements of the supply chain, which includes:

- ensuring uninterrupted functioning of the production system[55];

- ensuring stable financial condition; providing analysis of business activity[56];

– information and communication reliability, accuracy and timeliness[57];

3) Logistics costs:

– costs for internal and external transportation[58];

– costs related to product quality (losses from insufficient quality, loss of sales, return of goods, etc.)[59];

- costs for cargo processing and storage[60];

– costs related to order procedures[61].

---

[54]Vojtov V., Kutiya O., Berezhnaja N., Karnaukh M., Bilyaeva, O. Modeling of reliability of logistic systems of urban freight transportation taking into account street congestion. Eastern-European Journal of Enterprise Technologies, 2019, 4(3 (100), 15–21. https://doi.org/10.15587/1729-4061.

[55]Sukati I., Hamid A.V., Baharun R., Yusoff R.Md The Study of Supply Chain Management Strategy and Practices on Supply Chain Performance, Procedia - Social and Behavioral Sciences, Volume 40, 2012, 225-233.

[56]Zagurskyi O.M. Supply chain management: a textbook. Kyiv: FOP Yamchynskyi O.V., 2023. 333.

[57]Kankam G., Kyeremeh E,, Som GNK, Charnor IT Information quality and supply chain performance: The mediating role of information sharing, Supply Chain Analytics, Volume 2, 2023, 100005

[58]Hajghasem M., Shojaie A.A. Optimal Routing in Supply Chain Aimed at Minimizing Vehicle Cost and Supply, Procedia Economics and Finance, Volume 36, 2016, 353-362.;Chowdhury P, Paul SK, Kaisar S, Moktadir MA. COVID-19 pandemic related supply chain studies: A systematic review. Transp Res E Logist Transp Rev 2021 Apr;148:102271. doi: 10.1016/j.tre.2021.102271. Epub 2021 Feb 13. PMID: 33613082; PMCID: PMC7881707.

[59]Castillo-Villar K.K., Smith NR, Simonton JL A model for supply chain design considering the cost of quality, Applied Mathematical Modelling, Volume 36, Issue 12, 2012, 5920-5935.; He Y., Yin S. Cost analysis in global supply chains, Operations Research Letters, Volume 48, Issue 5, 2020, 658-665.

[60] Ramos E.,Dien S.,Gonzales A.,Chavez M.,Hazen B.Supply chain cost research: a bibliometric mapping perspective,Benchmarking: An International Journal, 2021, Vol. 28 No. 3, pp. 1083-1100.https://doi.org/10.1108/BIJ-02-2020-0079.;Tikwayo LN, Mathaba TND Applications of Industry 4.0 Technologies in Warehouse Management: A Systematic Literature Review. Logistics 2023, 7, 24. https://doi.org/10.3390/ logistics7020024.

[61]Pereira VJ, Vieira SFA, Capucho PHP, Vera Suguihiro LT, Tridapalli JP Cost management in the supply chain: An analysis of the costs of different types of municipal procurement, Social Sciences & Humanities Open, Volume 5, Issue 1, 2022, 100260. ; Venegas BB, Ventura JA A two-stage supply chain coordination mechanism considering price sensitive demand and quantity discounts, European Journal of Operational Research, Volume 264, Issue 2, 2018, 524-533.

4) Product quality:

- accuracy and reliability of forecasting[62];

- cases of loss, theft, damage, etc[63].

5) Logistics cycle time:

– time of order cycle components[64];

- stock replenishment time[65];

- time of processing orders by consumers[66];

- order delivery time[67];

- the time of order preparation and completion[68];

– the time of the production and technological cycle[69];

- the time of the material resources procurement cycle[70];

5) Completeness:

- accuracy and timeliness of forecasting demand for products[71];

---

[62]Abolghasemi M., Beh E., Tarr G., Gerlach R. Demand forecasting in supply chain: The impact of demand volatility in the presence of promotion, Computers & Industrial Engineering, Volume 142, 2020, 106380.

[63]Bosona T., Gebresenbet G. The Role of Blockchain Technology in Promoting Traceability Systems in Agri-Food Production and Supply Chains. Sensors 2023, 23, 5342.https://doi.org/10.3390/s23115342.; Verma M., Plaisier C., van Wagenberg CPA, Achterbosch T. A Systems Approach to Food Loss and Solutions: Understanding Practices, Causes, and Indicators. Sustainability 2019, 11, 579.https://doi.org/10.3390/su11030579

[64]Yang J., Xie H., Yu G., Liu M., Achieving a just–in–time supply chain: The role of supply chain intelligence, International Journal of Production Economics, Volume 231, 2021, 107878.; Esmaeili-Najafabadi E., Nezhad MSF, Pourmohammadi N., Honarvar M., Vahdatzad M. AND. A joint supplier selection and order allocation model with disruption risks in centralized supply chain, Computers & Industrial Engineering, Volume 127, 2019, 734-748.

[65]Chang W.-S., Lin Y.-T. The effect of lead-time on supply chain resilience performance, Asia Pacific Management Review, Volume 24, Issue 4, 2019, 298-309.

[66]Cannella S. Order-Up-To policies in Information Exchange supply chains, Applied Mathematical Modelling, Volume 38, Issue 23, 2014, 5553-5561.

[67]Hammami R., Frein Y., Albana AS Delivery time quotation and pricing in two-stage supply chains: Centralized decision-making with global and local managerial approaches, European Journal of Operational Research, Volume 286, Issue 1, 2020, 164-177 .;Ha NT,Akbari M., Au B.Last mile delivery in logistics and supply chain management: a bibliometric analysis and future directions",Benchmarking: An International Journal, 2023, Vol. 30 No. 4, pp. 1137-1170.https://doi.org/10.1108/BIJ-07-2021-0409.

[68]Gunasekaran A. Ngai EWT Build-to-order supply chain management: a literature review and framework for development, Journal of Operations Management, Volume 23, Issue 5, 2005, 423-445.

[69]Liu L., Song W., Liu Y. Leveraging digital capabilities toward a circular economy: Reinforcing sustainable supply chain management with Industry 4.0 technologies, Computers & Industrial Engineering, Volume 178, 2023, 109113.; Vegter D., van Hillegersberg J., Olthaar M. Supply chains in circular business models: processes and performance objectives, Resources, Conservation and Recycling, Volume 162, 2020, 105046.

[70]Fattahi M. Resilient procurement planning for supply chains: A case study for sourcing a critical mineral material, Resources Policy, Volume 74, 2021, 101093.;Matopoulos A.,Barros AC,van der Vorst JGAJ(J)Resource-efficient supply chains: a research framework, literature review and research agenda,Supply Chain Management, 2015, Vol. 20 No. 2, pp. 218-236.https://doi.org/10.1108/SCM-03-2014-0090.

[71]Tadayonrad Y., Ndiaye A.V. A new key performance indicator model for demand forecasting in inventory management considering supply chain reliability and seasonality, Supply Chain Analytics, Volume 3, 2023,

- implementation of the production schedule[72];

- accuracy of order parameters[73];

- complete satisfaction of the order[74].

According to these parameters, it is proposed to evaluate the reliability of the supply chain based on the calculation of the integral reliability indicator[75] according to the following formula:

$$Y = \sum_{i=1}^{m} \beta_i \times p_i \times N_i, \qquad (1.9)$$

where βi –e weighting coefficients of reliability indicators;

p_i – the probability of achieving the required values of reliability indicators;

N_i – the level of reliability indicators;

m – the number of reliability indicators of the logistics chain.

The following process for planning activities that ensure the reliability of the supply chain is also proposed:

1) defining the goals and objectives of the supply chain;

2) formation of evaluation criteria for achieving the set goal;

3) monitoring and logistic analysis of the results of the functioning of the supply chain;

4) analysis of facts affecting the reliability of the supply chain;

5) drawing up a supply chain unreliability risk profile (comprehensive risk analysis);

100026.; Abolghasemi M., Hurley J., Eshragh A., Fahimnia V. Demand forecasting in the presence of systematic events: Cases in capturing sales promotions, International Journal of Production Economics, Volume 230, 2020, 107892.

[72] Parwani V., Hu G. Improving Manufacturing Supply Chain by Integrating SMED and Production Scheduling. Logistics 2021, 5, 4.https://doi.org/10.3390/logistics5010004.; Yaghin RG Enhancing supply chain production-marketing planning with geometric multivariate demand function (a case study of textile industry), Computers & Industrial Engineering, Volume 140, 2020, 106220.

[73]Pastore E., Alfieri A., Zotteri G., Boylan JE The impact of demand parameter uncertainty on the bullwhip effect, European Journal of Operational Research, Volume 283, Issue 1, 2020, 94-107.

[74]Omoruyi O., Mafini C. Supply Chain Management and Customer Satisfaction in Small to Medium Enterprises. Studia Universitatis Babe-Bolyai Oeconomica. 2016. 61. 10.1515/subboec-2016-0004.; Asha A.A., Dulal M., Ahashan Habib Dr. The influence of sustainable supply chain management, technology orientation, and organizational culture on the delivery product quality-customer satisfaction nexus, Cleaner Logistics and Supply Chain, Volume 7, 2023, 100107.

[75] Kumar D.,Sony G.,Kazancoglu Y.,Rathore APSOn the nature of supply chain reliability: models, solution approaches and agenda for future research,International Journal of Quality & Reliability Management, 2023. Vol. ahead-of-print No. ahead-of-print.https://doi.org/10.1108/IJQRM-08-2022-0256.

6) the choice of strategy and risk management techniques to ensure the reliability of the supply chain;

7) development of a program of actions aimed at neutralization or minimization of possible negative consequences of the risk[76].

Thus, an approach that takes into account the safety of business processes in supply chains in conditions of uncertainty (or partial uncertainty) is developing in scientific circles, based on the theory of risk management and the theory of complex systems.

1.3 Methods and capabilities of supply chain reliability assessment

Modern business is in a stage of uncertainty, it has to deal with many risks arising from wars in Ukraine and Israel, rising energy prices, shortages of materials and components, tensions around Taiwan and Korea, quarantine in China, the COVID-19 pandemic and various natural disasters.

A combination of external adverse factors with internal supply chain problems related to: price fluctuations; arbitrarily increase the supply batches; deviations from the planned terms and volumes of production and market turbulence, which causes additional uncertainty in the business procedures of organizations[77] lead to disruptions or failures in supply chains, and therefore to a decrease in the reliability of supplies and an increase in overall costs, both for the participants in the supply chains and for the end users of their products.

Specialists of the KYU market research consulting firm have published the 2023 supply chain risk barometer, which includes 10 critical risks of the modern world (Fig. 1.10).

[76]Chen L, Dui H, Zhang S. A resilience measure for supply chain systems considering the interruption with the cyber-physical systems, Reliability Engineering & System Safety, Volume 199, 2020, 106869.

[77]Wang G. Dou W., Zhu W., Zhou N. The effects of firm capabilities on external collaboration and performance: The moderating role of market turbulence Journal of Business Research, 68 (9), 2015, 1928-1936.

Fig. 1.10 Barometer of supply chain risks 2023

Source: [BAROMETER] What Are the 10 Supply Chain Risks for 2023. URL.https://emag.directindustry.com/2023/01/27/barometer-what-are-the-10-supply-chain-risks-for-2023/

Therefore, the classification of methods of increasing the reliability of supply chains should be useful not only in the theoretical, but also in the practical aspect. The proposed classification allows you to make a reasonable choice of a method of managing the reliability of supply chains in specific conditions or for a specific business process.

Table 1.7 – Relationship of the stages of the functional cycle of supply logistics with elements of reliability and methods of their provision

Stages of supply logistics	Elements of reliability	Methods of ensuring reliability
1. Processing of the production order for the supply of material and technical resources	Reliability of demand forecasting	Choosing the most effective method of forecasting demand
2. Determination of production needs in material and technical resources and production services	Reliability of planning the need for material and technical resources	The choice of the method of calculating the need: the direct account method, the calculation of the need based on the data on the recipe composition of the manufactured products, the calculation of the need based on the normative terms of wear.
3. Selection of raw material suppliers	Reliability of suppliers	Selection of the most reliable suppliers based on analytical and expert methods.
4. Placing an order for the purchase of material and technical resources and their delivery	Reliability of the order and procurement management system	Choosing the optimal inventory management strategy. Choosing the optimal type of procurement. Selection of optimal delivery conditions.
5. Completing the order and shipment of material	Reliability of supplies	Supplier performance evaluation based on KPIs

and technical resources		
6. Delivery of material and technical resources	Reliability of delivery	Planning optimal routes for cargo delivery. The choice of the most effective method of ensuring the preservation of cargo (choice of packaging, transport container, method of carrying out loading and unloading operations, etc.)
7. Qualitative and quantitative acceptance of material and technical resources	Reliability of input control	Choosing the most effective method of quality and quantity control

Source: compiled by the authors

In an unpredictable business environment, the flexibility and reliability of firms plays a crucial role in maintaining their competitiveness[78]. That is, the importance of improving reliability as one of the key characteristics of the efficiency of supply chains is obvious. Even one of the key points of the 7P logistics concept provides for the requirement to ensure the reliability of supplies (according to experts, the level of reliability should be at least 97%). Also, the level of supply chain reliability is included in the World Bank's Logistics Performance Index (LPI).[79].

[78]Lee O.-K., Sambamurthy V., Lim KH, Wei KK How does IT ambidexterity impact organizational agility? Information Systems Research, 26 (2), 2015, 398-417.

[79]Koons-Stapf A. Reliability & Maintainability Applications in Logistics & Supply Chain. 2015. 10.1109/RAMS.2015.7105108.

In general, all existing methods for reliability assessment can be divided into three types: analytical methods, optimization methods, and simulation modeling methods.

Analytical methods

- are based on calculating the reliability of the system using mathematical formulas or algebraic expressions.
- are simple to calculate and are usually used to assess theoretical (actual) reliability.

Optimization methods

- based on mathematical programming methods for solving optimization problems of calculating the reliability of the supply chain.
- provide higher accuracy of the solution than calculations using analytical methods, allow to determine even practical reliability based on direct calculation.

Simulation methods

- are based on software modeling methods that allow you to simulate a real process in the supply chain and determine its reliability over time.
- allow you to describe the random nature of the process in dynamics, their application is often combined with optimization methods to verify the required level of reliability under the influence of random factors.

Fig. 1.11 Methods for assessing process reliability in the supply chain

Source: compiled by the authors

However, when it comes to the functioning of complex systems (which undoubtedly includes supply chains) in the sense of their reliability, among the methods of their description, the following are distinguished:

– structural scheme of the system;

– structural redundancy;

– functions of algebra of logic (FAL);

– the methods are built on the use of theorems of the theory of probabilities;

- system-analytical approach.

Let's consider them in more detail.

Structural diagram of the system.

In it, each element of a complex system is depicted in the form of a geometric figure, most often a rectangle. The rectangles are connected by lines in such a way that the resulting structural diagram reflects the conditions of system reliability and operability.

The reservation of elements is carried out by the methods of constantly included reserve, substitution and fractional multiplicity m=1/2. The structural diagrams clearly show the conditions of reliable operation of the system. The system in fig. 1.12-a is reliable if all its elements are working.

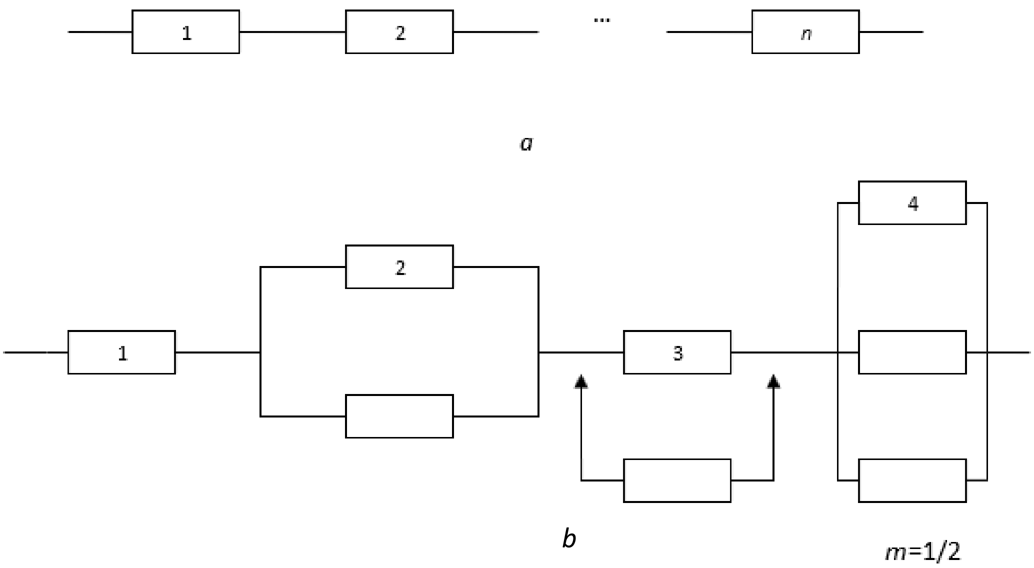


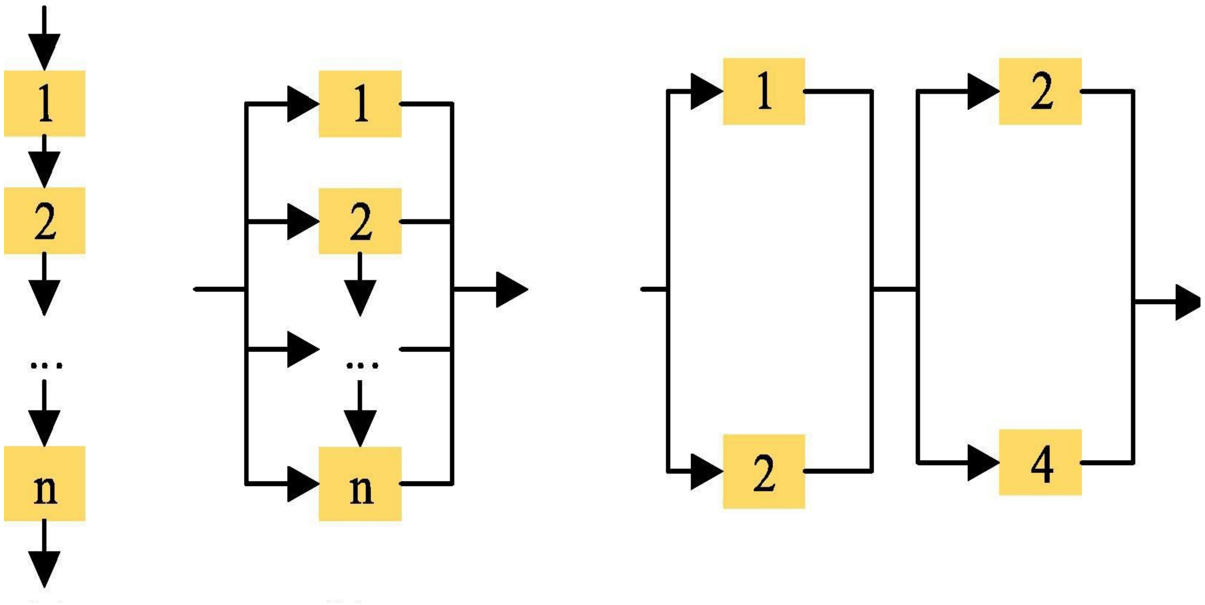
Fig. 1.12 Structural diagrams of the system

a – unreserved b – reserved

Source: compiled by the authors

The failure of any element disrupts the performance of the system, its failure occurs. The system in fig. 1.12-b is operational if element 1 and any one element of duplicated pairs, as well as any two elements out of three reserved with fractional multiplicity m=1/2, are valid.

The main advantage of this method is clarity. Its disadvantage is far from complete information about the functioning of the system.And taking into account the fact that the supply chain model expresses the actual supply relations between neighboring manufacturers and suppliers (regardless of the structure of the supply chain, see Fig. 1.13), such a scheme can be interpreted as a system in which elements follow one another.



a b c

Fig. 1.13 Supply chain model with different structure

Source: Zhang M., Chen J., Chang SH., An adaptive simulation analysis of reliability model for the system of supply chain based on partial differential equations, Alexandria Engineering Journal, Volume 59, Issue 4, 2020, 2401-2407.

Here (Fig. 1.13-a), the element is considered to be connected in series, if disturbances in its operation lead to disturbances in the operation of the entire circuit in general. When all elements of the circuit are connected in series, one failure is enough to completely stop the operation of the system.

The probability of failure-free operation of such a supply chain can be determined by the formula:

$$P_c = P_1 \times P_2 \times P_n = \prod_{i=1}^{n} P_i \qquad (1.10)$$

where: Pi is the probability of failure-free operation of the i-th element of the system.

And if n components are needed by downstream manufacturers, n suppliers will supply them. In addition, the supply chain is similar to serial systems because it is unable to continue production due to the absence of any of the components. Therefore, its structural function is calculated according to equation (1.11)

$$\varphi(x) = \prod_{i=1}^{n} x_i = min\{ x_1 , x_2, \ldots , x_n\}, \qquad (1.11)$$

where: x – costs of enterprises participating in the supply chain.

An element that does not lead to system failure when its operation is disturbed is called parallel connected (rice. 1.13-b), and a system in which at least one component is supplied by several suppliers in a parallel system. With such a configuration, system failure is generally possible only in case of failure of all parallel connected elements of the system. The probability of such an event is equal to:

$$Q_c(t) = Q_1(t) \times Q_2(t) \times Q_n(t) \qquad (1.12)$$

where: Qi(t) is the probability of failure of the i-th element of the system during time t. The probability of trouble-free operation in this case can be determined by the following formula:

$$P_c(t) = 1 - \prod_{i=1}^{n}(1 - P_i(t)), \qquad (1.13)$$

and the structural function according to equation (1.14)

$$\varphi(x) = \coprod_{i=1}^{n} x_i = min\{x_1, x_2, \ldots , x_n\}, \qquad (1.14)$$

Where symbol $\coprod$ indicates that equation (1.15) holds for any x

$$\coprod_{i=1}^{n} p_i = 1 - \prod_{i=1}^{n}(1 - p_i), \qquad (1.15)$$

Figure 1.13-c shows a complex (parallel-serial) system, or a multi-channel network in which disruptions in one supply horizon can be compensated by other supplies.

The probability of failure-free operation of such a supply chain is determined by the formula:

$$P_0 = 1 - \prod_{i=1}^{m} (1 - \prod_{j=1}^{n} p_j)_i \tag{1.16}$$

where: n is the number of suppliers,

m is the number of supply chains (channels),

The structural function of a complex supply chain system is represented by equation (1.17)

$$\varphi(x) = (x_1 \coprod x_2)(x_3 \coprod x_4 = \lfloor 1 - (1 - x_1)(1 - x_2) \rfloor \lfloor 1 - (1 - x_3(1 - x_4) \rfloor, \tag{1.17}$$

So, from the point of view of reliability, it becomes obvious that only when all participants of the supply chain are in a normal state and have minimal (allowable) costs for the promotion of goods to the consumer, and the structure of the supply chain is perfect, the supply chain can be considered effective. Therefore, the reliability of the supply chain is completely determined by the reliability of the companies involved in the promotion of the product and the structure of the supply chain system. And the failure of any of them will not improve the reliability of the supply chain system[80].

A perfect or near-perfect supply chain structure can significantly increase its ability to prepare for, respond to, and recover from disruptions. Thus, an extended supply chain with multiple tiers of suppliers can be less reliable because a failure at one tier can cause a cascading effect throughout the network, commonly known as a ripple effect. On the other hand, an extended supply chain with a simpler structure and fewer levels can exhibit

[80]Zhang M., Chen J., Chang SH., An adaptive simulation analysis of reliability model for the system of supply chain based on partial differential equations, Alexandria Engineering Journal, Volume 59, Issue 4, 2020, 2401-2407.

greater stability, maintaining a steady state even in the face of disruptions[81]. Alternatively, a centralized supply chain network with a single source of supply may be more vulnerable to failure, as a failure at a central node can significantly affect the entire network, affecting all connected nodes at multiple sites.

In contrast, a decentralized supply chain with multiple sources of supply can be more resilient because a failure at one node is easier to isolate and contain. In addition, the structure of the supply chain can affect how long it takes to restore it to a standard level. For example, supply chains with multiple alternative transportation routes can recover from disruptions more quickly than supply chains with only one route.

A well-structured network can ensure the rapid transfer of information and resources, mitigating the effects of failures. Which in turn makes it easier to find alternative suppliers or transport routes quickly, reducing downtime and costs associated with supply chain disruptions[82].

Structural reservation.

This is a method of increasing reliability by including backup units capable of performing its functions in the event of failure of the main device. All reserve methods and ways to include reserve can be reduced to three methods[83]:

– general redundancy, in which identical backup systems are connected in parallel to maintain system reliability;

– separate or element-by-element redundancy in which the system redundancy occurs by using separate backup devices (system elements);

– combined or mixed reservation in which general and separate reservation are used in the same system.

---

[81]Li Y., Zobel CW Exploring supply chain network resilience in the presence of the ripple effect, International Journal of Production Economics, Volume 228, 2020, 107693

[82] Hou Y., Wang X., Wu YJ, He P. How does the trust affect the topology of supply chain network and its resilience? An agent-based approach Transportation Research Part E: Logistics and Transportation Review, 116, 2018, 229-241.

[83]Cheaitou A., Cheaytou R. A two-stage capacity reservation supply contract with risky supplier and forecast updating, International Journal of Production Economics, Volume 209, 2019, 42-60.

There are also two types of backup: always-on backup and replacement backup[84].

The structural diagrams of these types of redundancy (reliability calculation diagrams) are shown in fig.1.14.

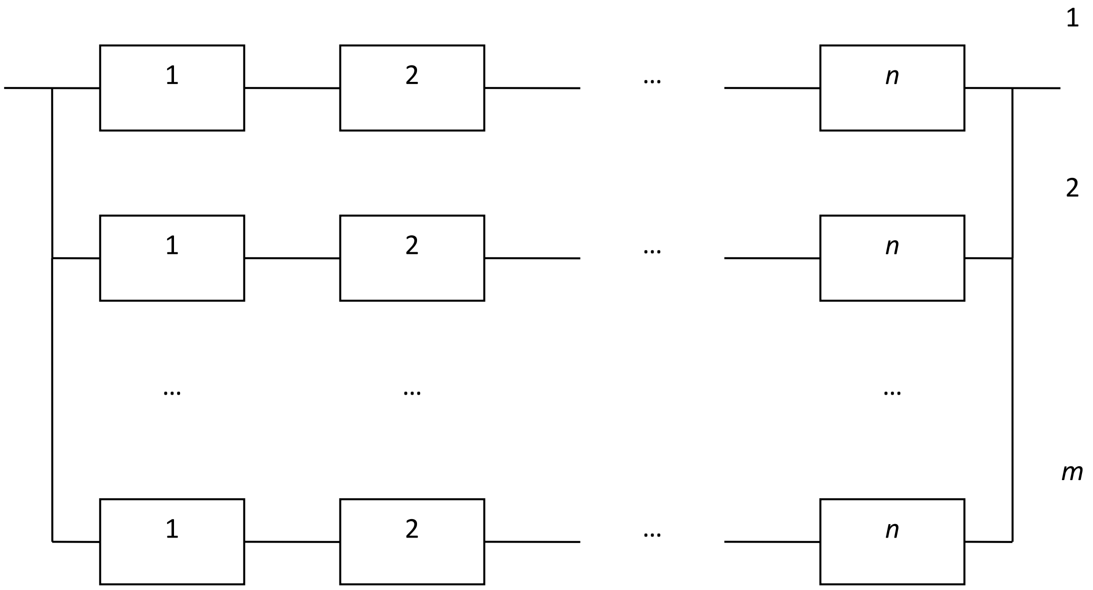


Fig.1.14-a General Redundancy with Always On Redundancy

Source: compiled by the authors

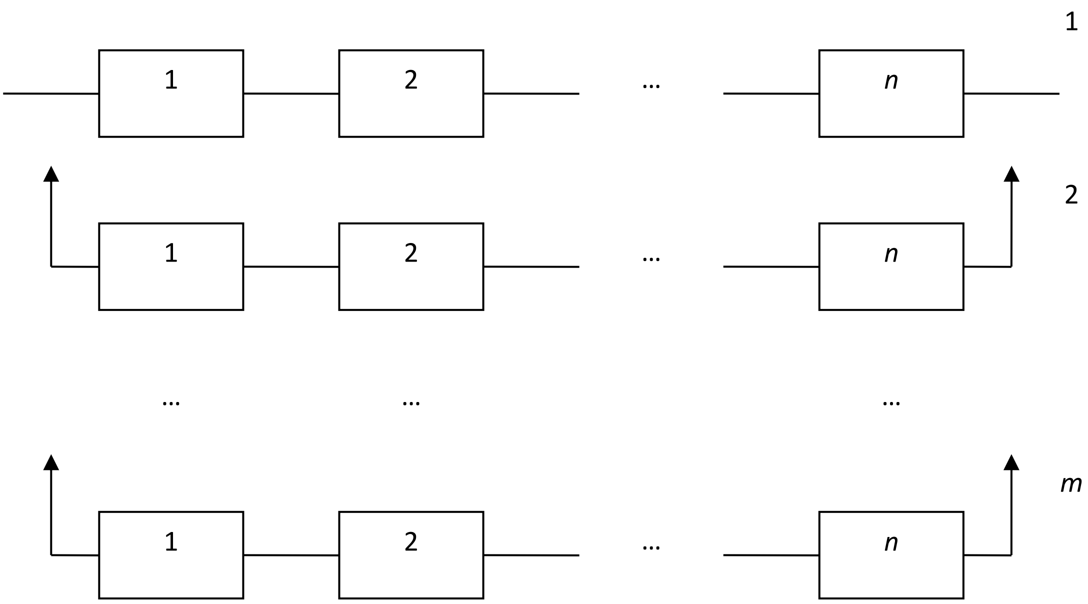


Fig. 1.14-b General reservation by substitution

Source: compiled by the authors

[84]Cajal-Grossi J., Del Prete D., Macchiavello R., Supply chain disruptions and sourcing strategies, International Journal of Industrial Organization, Volume 90, 2023, 103004.

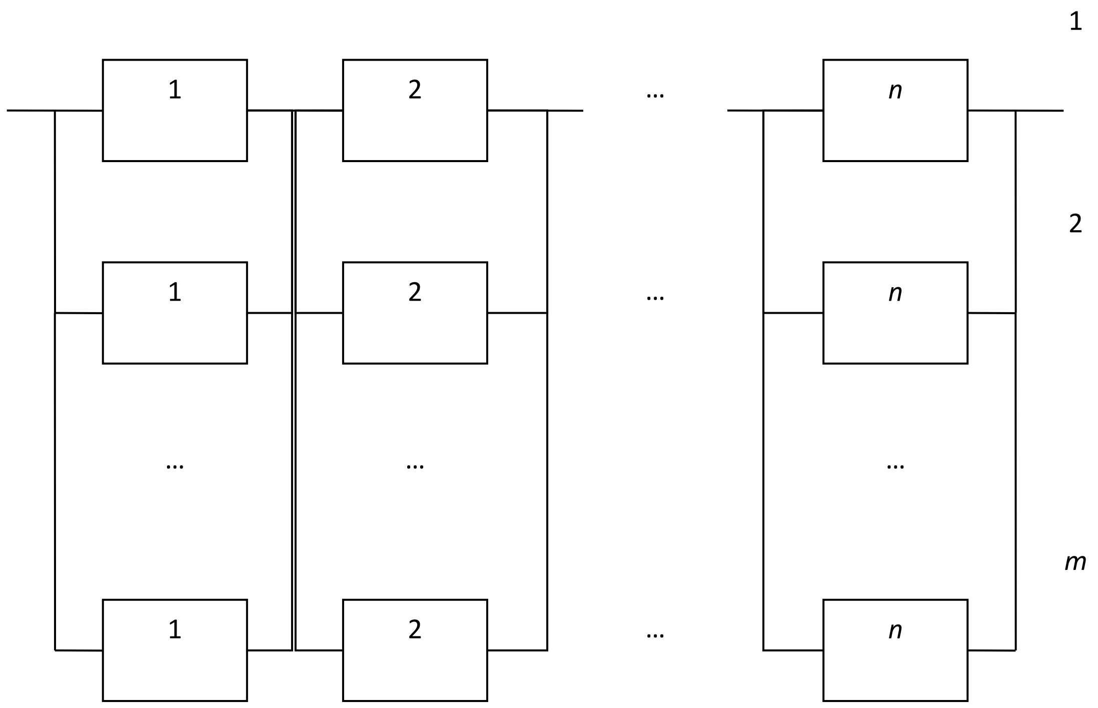


Fig. 1.14-c Split redundancy with always-on redundancy

Source: compiled by the authors

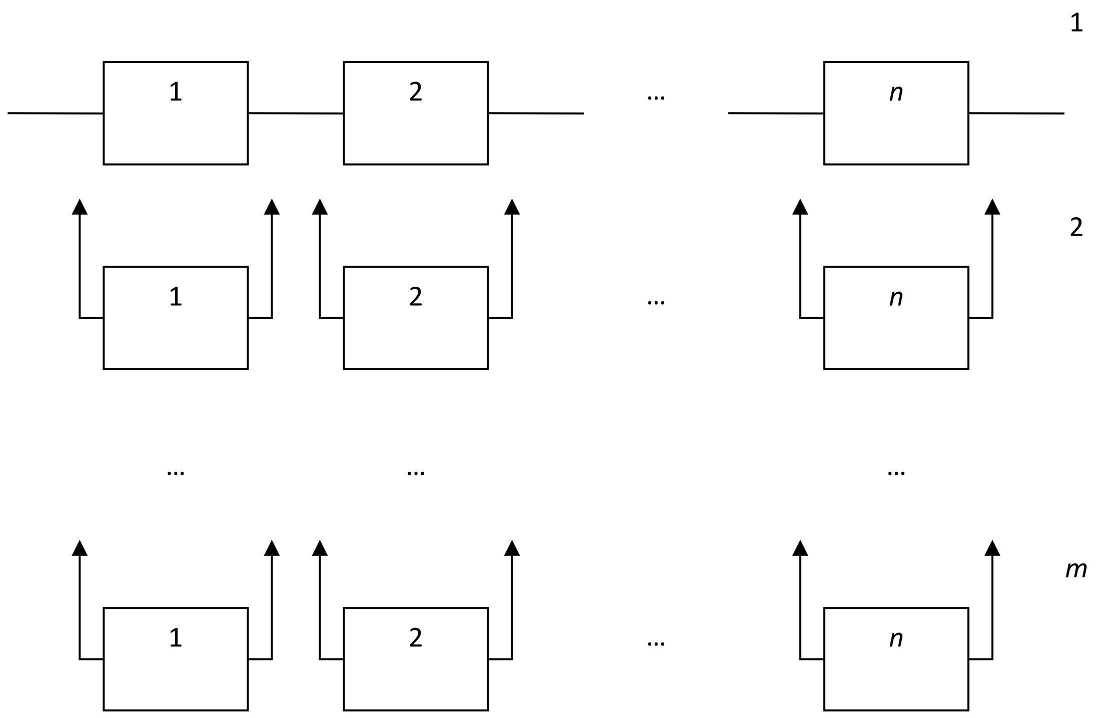


Fig. 1.14-d Separate reservation by substitution

Source: compiled by the authors

n is the number of elements of the non-reserved system (contractors of the supply chain),

m is the number of backup systems (supply channels).

In the case of general redundancy with the reserve always on (Fig. 1.14-a), the elements of the i-th row ($i =\overrightarrow{\leftarrow} 1,2,\ldots,m$) are placed sequentially, therefore the time to failure of the subsystem composed of elements of the i-th row is equal to .$T_i = \min_{j=1,2,\ldots,n} T_{i,j}$Since the entire system is a parallel connection of these subsystems, the time to failure of the system is equal to , hence the time of system failure-free operation is equal to:

$$T_c = \max_{i=1,2,\ldots,m} T_i$$

$$T_c = \max_{i=1,2,\ldots,m} \min_{j=1,2,\ldots,n} T_{i,j}, \tag{1.18}$$

and, the probability of trouble-free operation is:

$$P_c(t) = 1 - \prod_{i=1}^{m}\left(1 - \prod_{j=1}^{n} P_{i,j}(t)\right), \tag{1.19}$$

According to general redundancy by substitution (Fig. 1.14-b), the elements of the i-th row also form a serial connection, therefore the time to failure of the subsystem composed of the elements of the i-th row is similar to the previous scheme ($i =\overrightarrow{\leftarrow} 1,2,\ldots,m$)$T_i = \min_{j=1,2,\ldots,n} T_{i,j}$.

And since the number of subsystems is greater than one, the time until the failure of the entire system is equal to the sum of the time before the failure of these subsystems, therefore, the time of the system's failure-free operation is equal to:

$$T_c = \sum_{i=1}^{m} T_i$$

$$T_c = \sum_{i=1}^{m} \min_{j=1,2,\ldots,n} T_{i,j} \tag{1.20}$$

and, the probability of trouble-free operation is:

$$P_c(t) = \sum_{i=1}^{m} f_1(t) \cdot f_2(t) \cdot \ldots \cdot f_{i-1}(t) \cdot P_i(t) \tag{1.21}$$

In the case of separate redundancy with the reserve always on (see Fig. 1.14-c), the elements of the j-th column form a parallel connection of elements, so the time to failure of the subsystem composed of the elements of the j-th column is equal to $(j =\rightleftarrows 1,2,\dots,n) T_j = \max_{i=1,2,\dots,m} T_{i,j}$.

And since the entire system is a serial connection of these subsystems, the time to system failure is equal to , therefore, the time of system failure-free operation is equal to:

$$T_c = \min_{j=1,2,\dots,n} T_j$$

$$T_c = \min_{j=1,2,\dots,n} \max_{i=1,2,\dots,m} T_{i,j} \qquad (1.22)$$

and, the probability of trouble-free operation is:

$$P_c(t) = \prod_{j=1}^{n} \left(1 - \prod_{i=1}^{m} \left(1 - P_{i,j}(t)\right)\right); \; (1.23)$$

With separate redundancy by substitution (see Fig. 1.14-d), the failure time of the subsystem formed by the elements of the jth column is equal to the sum of the time until its elements fail $(j =\rightleftarrows 1,2,\dots,n) T_j = \sum_{i=1}^{m} T_{i,j}$.

Since the entire system is a serial connection of these subsystems, the time to system failure is equal to , hence the time of system failure-free operation is equal to:

$$T_c = \min_{j=1,2,\dots,n} T_j$$

$$T_c = \min_{j=1,2,\dots,n} \sum_{i=1}^{m} T_{i,j} \qquad (1.24)$$

and, the probability of trouble-free operation is:

$$P_c(t) = \prod_{j=1}^{n} \sum_{i=1}^{m} f_1(t) \cdot f_2(t) \cdot \ldots \cdot f_{i-1}(t) \cdot P_i(t). \; (1.25)$$

The main drawback of this method isa rather time-consuming calculation process that requires the involvement of appropriate software tools, especially for large values of n and m.

However, structural diagrams are not mathematical models of the functioning of the system and do not provide complete information about the system, so we should proceed to consider a method that more accurately describes the functioning of complex systems, namely the functions of the algebra of logic.

Algebra of logic function (FAL).

The basic idea behind FAL is to identify a logical formula as a polynomial in such a way that the truth-valued function induced by the formula can be understood as a polynomial function[85].

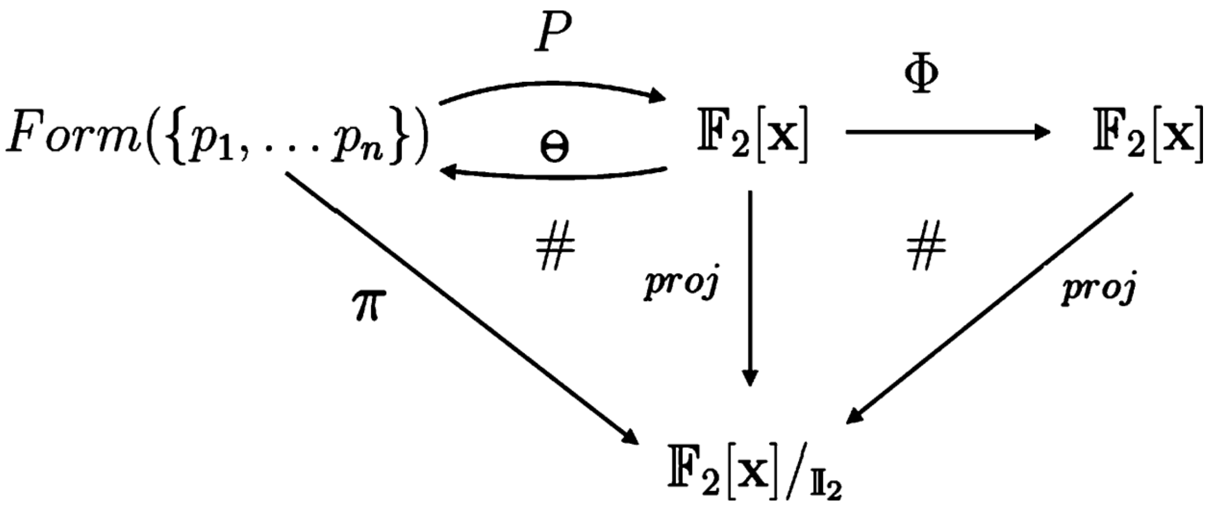


Fig. 1.15 Zconnection between structures in FAL

Source: Alonso-Jiménez JA, Aranda-Corral, Joaquín Borrego-Díaz GA, Fernández-Lebrón MM, Hidalgo-Doblado MJ A logic-algebraic tool for reasoning with Knowledge-Based Systems, Journal of Logical and Algebraic Methods in Programming, Volume 101, 2018 , 88-109.

The essence of the FAL method is as follows.

The state of the system elements is coded by binary variables: "1" (the element is working), "0" (failure in the functioning of the element). Then the functioning of the system can be described with the help of FAL, using conjunction, disjunction and inversion operations. With the help of FAL, the condition of the system's operability is recorded due to the operability of its

[85]Alonso-Jiménez JA, Aranda-Corral, Joaquín Borrego-Díaz GA, Fernández-Lebrón MM, Hidalgo-Doblado MJ A logic-algebraic tool for reasoning with Knowledge-Based Systems, Journal of Logical and Algebraic Methods in Programming, Volume 101, 2018 , 88-109.

elements. The system is in a working condition, provided that all its elements are working. For clarity, consider a system with three unequally reliable elements (Fig. 1.16).

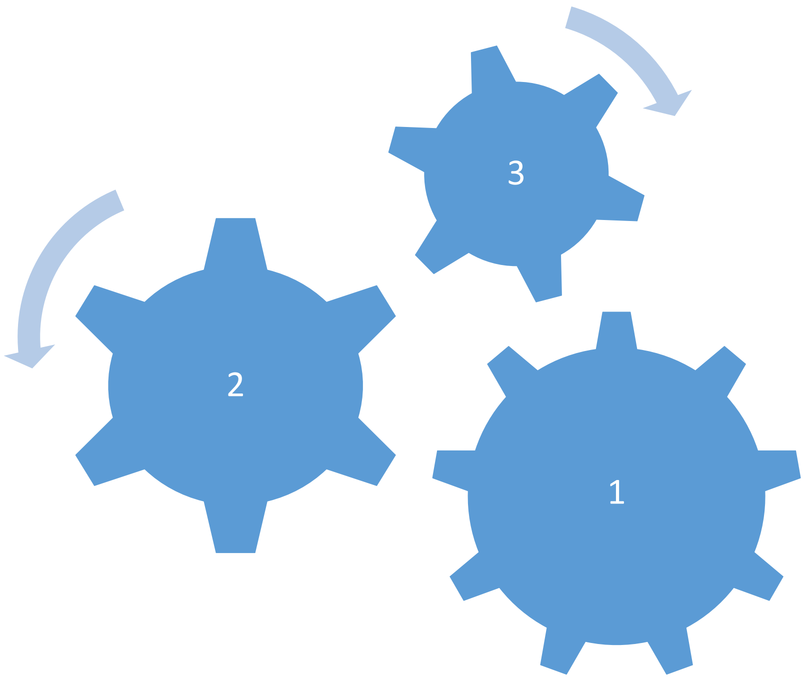


Fig. 1.16 Structural diagram of the system

Source: compiled by the authors

The system will be in working condition only if all elements are in good condition. If elements 1 and 2 or 1 and 3 are working in Fig. 1.15, then the FAL corresponding to the function of performance will look as follows:

$$y(x_1, x_2, x_3) = x_1, x_2, x_3 \vee x_1, \overline{x_2}, x_3 \vee x_1, x_2, \overline{x_3} \qquad (1.26)$$

where: x_i is the working condition of the i-th element of the system;

$\overline{x_i}$ is the state of failure of the i-th element of the system.

The resulting FAL is transformed so that it contains members that correspond to favorable hypotheses of the system's proper operation. That is, the perfect disjunctive normal form (DDNF) is determined for a specific FAL obtained from the truth table that corresponds to the operational state of the system (table).

Table 1.8 - Truth table

x1	x2	x3	in
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Source: compiled by the authors

In FAL, instead of binary variables xi and respectively, the probabilities of failure-free operation pi and the probability of failure qi are substituted.$\overline{x_i}$The signs of conjunction and disjunction are replaced by algebraic multiplication and addition, and the resulting expression will be the probability of faultless operation of the system Pc(t). In the analyzed example, the mathematical record of the probability of fault-free operation of the system has the form:

$$Pc(t) = p_1(t)q_2(t)p_3(t) + p_1(t)p_2(t)q_3(t) + p_1(t)p_2(t)p_3(t) \tag{1.27}$$

The advantage of working with FAL is that it is possible to isolate several failures and describe different states of the supply chain, which cannot be done with conventional approaches. In relation to the system, consider two incompatible events that form a complete group of events:

- event A, which consists in maintaining the system's operability under certain conditions for a certain period of time;

- event B, opposite to event A, as it consists in the manifestation of refusal.

With the condition of a complete group of events:

$$P(A) + P(B) = P(A) + P(\bar{A}) = 1 \tag{1.28}$$

For each element of the system, a similar group of events is considered, but if element failures affect the system's operability in different ways, then several inoperable states can also be selected for an element failure event. Different types of failures occurring in the operation of an element are considered as incompatible events, since the simultaneous occurrence of two types of failures in one element is unlikely and this probability can be neglected.

But the logical-probabilistic method of calculating the reliability of complex systems has a number of disadvantages. For example, if it is impossible to make FAL and DDNF, then it will not be possible to find the probability of fault-free operation of the system. Compilation of FAL and DDNF may not be possible if the probability of failure-free operation of system elements is not known in advance or is a random value and if the intensity of failures increases in case of failure of one of the system elements operating in parallel. Therefore, in addition to FAL, during the analysis of the reliability of logistics systems, methods based on the use of probability theory theorems are used (hypothesis screening methods; methods using classical probability theory theorems; methods of minimal paths and minimal intersections).

The methods are based on the use of theorems of probability theory

Most often, when analyzing the reliability of logistics systems, the following methods are used, based on the application of theorems of probability theory:

- hypothesis screening method;
- a method based on the application of classical theorems of probability theory;
- method of minimal paths and minimal sections[86].

[86]Chen L., Dong T., Peng J., Ralescu D. Uncertainty Analysis and Optimization Modeling with Application to Supply Chain Management: A Systematic Review. Mathematics 2023, 11, 2530. https://doi.org/10.3390/math11112530.

It is convenient to use them to calculate the reliability of serial, parallel, serial-parallel and other schemes, based on the assumption of mutual independence of the duration of fault-free operation of system elements. In this case, based on the theorems of addition and multiplication of probabilities and the formula of total probability, it is possible to formulate expressions for the probability of fault-free operation of the system.

The process of forming a logistic system reliability model is based on the initial data relating to the processes taking place in the system, indicating the relationships between them; a list of all violations and failures that occurred in the system during a certain period of time (with an indication of the amount of the losses caused).

The further algorithm includes the following points:

1. Study of a typical sequence of events in the system. The number of main events identified by the researcher depends on the complexity of the system and the accuracy requirements of the model.

2. Consideration of each AI event from the standpoint of the probability of occurrence of violations in this event and probable losses from these violations. These values can be determined using accumulated statistical data.

3. Consolidation of the resulting structure by selecting complex events Ai.

4. Calculation of the amount of losses arising from violations in events Ai, taking into account the probabilities of occurrence of each event included in Ai.

5. Analysis of the influence of emerging failures on the magnitude of possible losses.

6. Formation of the objective function, which reflects the dependence between the probability of the apparent occurrence of each complex event and the level of possible losses from its occurrence.

7. Restrictions are introduced:

– formal limitation of the upper value of the probability of correct functioning of the system: PA≤1.

– limiting the probability values of the correct functioning of individual elements of the system

$$\begin{cases} p_1 \leq P_1 \\ p_2 \leq P_2 \\ \quad \dots \\ p_n \leq P_n \end{cases}, \qquad (1.28)$$

where: p1, p2, ..., pn are the probabilities of complex events A1, A2, ..., An;

P1, P2, ..., Pn are the maximum possible levels of reliability of the functioning of individual elements of the system.

8. Assessment of economic limitations determined by the permissible amount of costs to ensure the required level of reliability.

9. Formation of the target function, which connects levels of reliability and possible material costs for its maintenance:

$$F = p_1, p_2, \dots p_n \rightarrow min \qquad (1.\ 29)$$

10. Construction of the problem taking into account the specified restrictions

$$\begin{cases} F_{(p_1,p_2,\dots p_n)} = C_{(p_1,p_2,\dots p_n)} + G_{(p_1,p_2,\dots p_n)} \\ p_1 \leq P_1 \\ p_2 \leq P_2 \\ p_n \leq P_n \end{cases}, \qquad (1.30)$$

where: C(p1, p2, ..., pн) – total losses arising due to violations in the occurrence of events An;

G(p1,p2,...,pn) – the total costs required to ensure the required level of reliability.

9. Calculation of pn values. For this, you can use analytical methods and rewrite the previous system (1.30) as follows

$$\begin{cases} \frac{dF_{(p_1, p_2, \dots p_n)}}{dp_1} \\ \frac{dF_{(p_1, p_2, \dots p_n)}}{dp_2} \\ \frac{dF_{(p_1, p_2, \dots p_n)}}{dp_n} \\ p_1 \leq P_1 \\ p_2 \leq P_2 \\ p_n \leq P_n \end{cases}, \tag{1.31}$$

The solution of the final system can be achieved using various analytical methods and applied computer programs.

System-analytical approach

In order to obtain a reliable structure of the system, it is also justified to use a system-analytical approach, which combines precise mathematical calculations performed on a personal computer with the use of the professional capabilities of the decision-maker. Here, the formal description of decision-making procedures is subordinated to the logical-structural analysis of transformations in the given schemes. In this case, decision tables and regulations, which are mandatory for all suppliers included in the supply chain, can serve as a model that formally describes decision-making procedures.

The result of reliability of supply is the growth of the effectiveness (efficiency) of the chain. Measuring supplier reliability and risk indicators is the basis for making management decisions within the product supply chain management system. Considering the reliability of the supplier's processes only at the level of the functional logistics cycle, we note that the order is considered fulfilled if it is implemented within the specified tolerance range (Fig. 1.17).

As emphasized above, the reliability indicator reflects the property of the system and its elements to function without failure under certain conditions. These processes can occur within a set time or within specified tolerances.

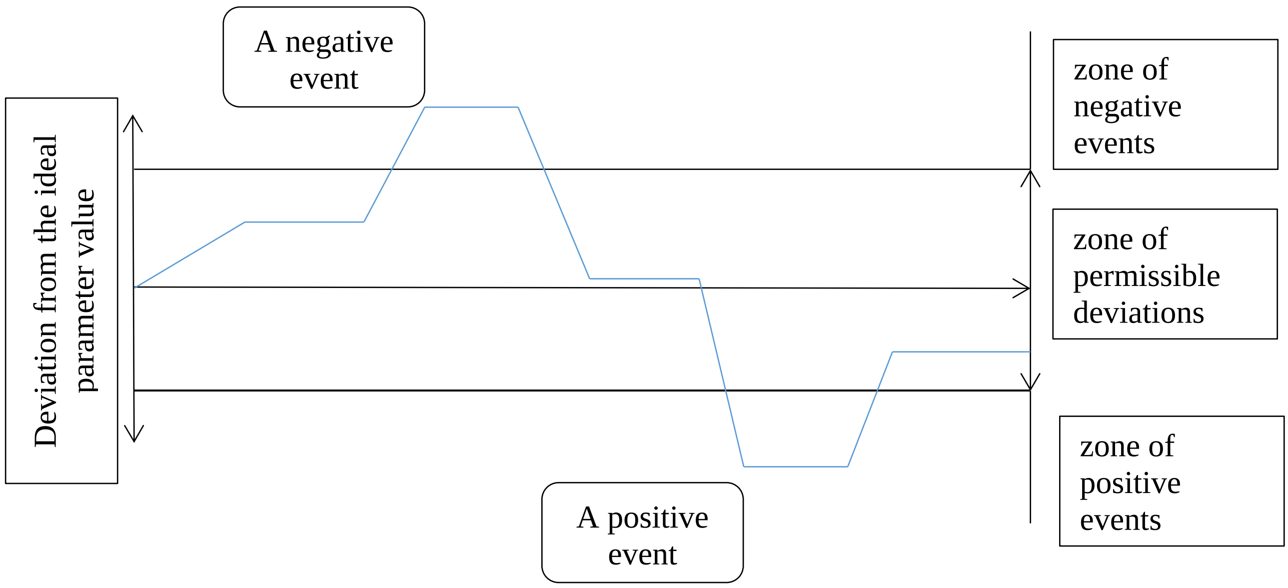


Fig. 1.17 Scheme of analysis of events during delivery

Source: compiled by the authors

The concepts of failure and failure caused by the influence of hazardous factors and the ability of elements to interact are closely related. Indicators of reliability of processes are data of probability values in the interval

$$0 \leq P \leq 1, \tag{1.32}$$

At the same time, "0" is an indicator of complete cessation of functioning (failure), and "1" is an indicator of full interaction.

Therefore, the reliability of supply processes under this approach means the probability that agreed results will be achieved in a certain period of time and within specified tolerances. The zone within the range of the zone of permissible deviations is a characteristic of reliable operation, which corresponds to an "acceptable" level of risk.

In addition, it should not be forgotten that reliable relations between partners in the supply chain are the most important factor of successful management, which allows them to have mutual trust in each other's capabilities and activities. Thus, in the operation of any integrated supply chain, increasing trust between partners and ensuring their reliability are critical factors for achieving sustainable success[87].

In our opinion, the problem of increasing the reliability of the company's supply activities is of particular importance in the modern market economy. After all, supply is a complex logistics function that encompasses the business processes of planning, procurement, inventory management, transportation, receiving, inbound quality control, and waste and return management. And if the distribution processes of finished products are primarily responsible for the overall efficiency of the supply chain, then the supply processes ensure its overall reliability. Therefore, taking into account the multifaceted nature of supply activities, the close relationship with suppliers and interaction with other departments of the company, there is a need to develop new planning methods that increase both the reliability of individual supplies and the reliability of the supply chain as a whole.

In recent years, the sustainability of supply processes has attracted increasing attention from both practitioners and the research community[88]. They all note that under the influence of globalization, the concept of sustainable development, modern information and communication technologies and the need to adopt lean operations, supply chains are becoming increasingly complex, and the business entities that make them up are increasingly dependent on each other.

[87]Ghazanfari M., Fatholla M. A comprehensive look at supply chain management, 1st edn. Iran Science and Technology University Publications, Tehran 2006

[88]Behzadi G., O'Sullivan MJ, Olsen TL On metrics for supply chain resilience European Journal of Operational Research, 287 (1) 2020, 145-158.

Hosseini S., Ivanov D. A new resilience measure for supply networks with the ripple effect considerations: A Bayesian network approach Annals of Operations Research, 1–27, 2019, 10.1007/s10479-019-03350-8.; Pettit TJ, Fikse J., Croxton KL Ensuring supply chain resilience: development of a conceptual framework. J. Business Logistics 2010, 31, 1–21.; Li Y., Zobel CW Exploring supply chain network resilience in the presence of the ripple effect, International Journal of Production Economics, Volume 228, 2020, 107693.;Martins VWB,Anholon R.,Leal Filho W.,Quelhas, OLGResilience in the supply chain management: understanding critical aspects and how digital technologies can contribute to Brazilian companies in the COVID-19 context.Modern Supply Chain Research and Applications, 2022, Vol. 4 No. 1, 2-18.https://doi.org/10.1108/MSCRA-05-2021-0005.; Niamat Ul, Fazio SA, Lawrence J., Gonzalez E., Jaradat R., Alvarado MS, Role of systems engineering attributes in enhancing supply chain resilience: Healthcare in context of COVID-19 pandemic, Heliyon, Volume 8, Issue 6, 2022 , e09592.; Novak DC, Wu Z., Dooley KJ Whose resilience matters? Addressing issues of scale in supply chain resilience Journal of Business Logistics, 42(3), 2021, 323-335.

So the macro structure of the supply chain[89]determined by the presence of groups of basic processes that form the frame of the chain and determine the relationships in it (Fig. 1.18).

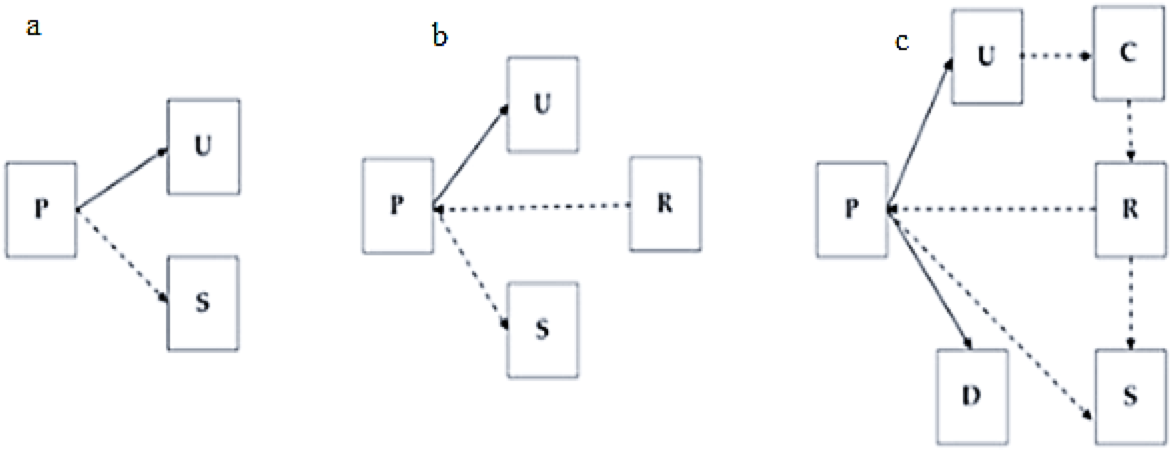


Fig. 1.18 Macrostructure of the supply chain

a – simple; b – extended; c – complete supply chain

Source: compiled by the authors

Block P includes the main types of activities related to procurement, production and distribution processes. Block U defines the markets and customers of the supply chain. Blocks (C; D; R; S) of reverse logistics operations such as collection (C), disposal (D), recovery (R) and secondary markets (S). All blocks form close relationships with each other (disjunctive and conjunctive), as a result of which complex and closely connected networks of supply chains become very vulnerable to failures in the work of their blocks and elements.

Figure 1.19 shows a failure tree for determining cause-and-effect relationships in the supply chain, showing which subsequent events initial failures can lead to.

[89]Benedito E., Martínez-Costa C., Rubio S. Introducing Risk Considerations into the Supply Chain Network Design. Processes 2020, 8, 743. https://doi.org/10.3390/pr8060743

The construction of the event tree begins with an undesirable event (for example, a refusal to supply the required amount of materials) and traces the reasons that can cause it.

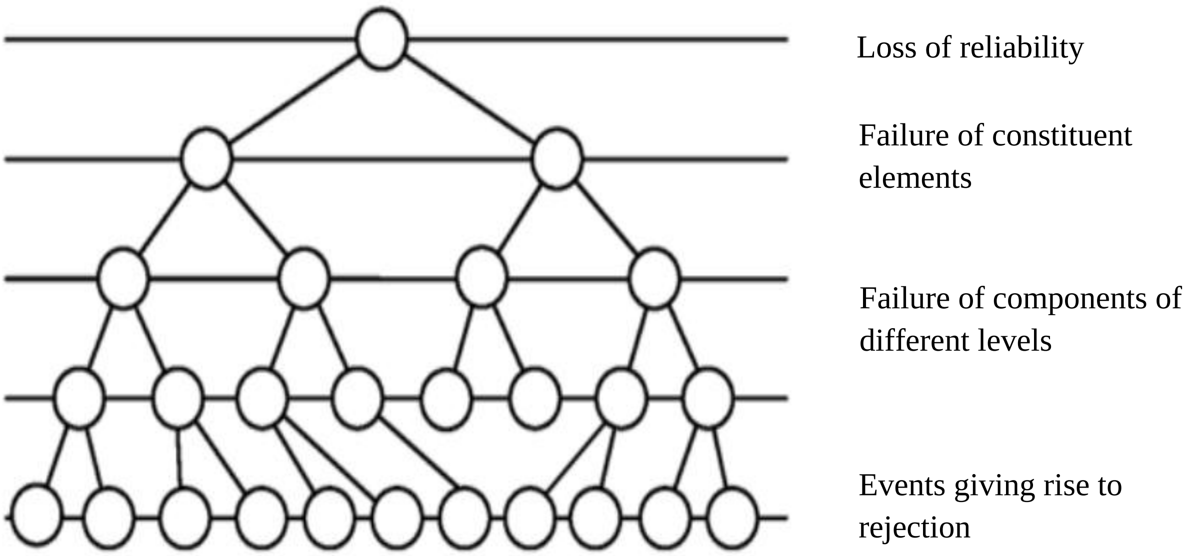


Fig. 1.19 Rejection tree

Source: compiled by the authors

For example, the supply chain will necessarily lose reliability if the following events occur simultaneously:

1) supply of products in an incomplete volume due to a decrease in the capacity of an industrial enterprise or a decrease in the capacity of logistics intermediaries;

2) decrease in the quality of products due to spoilage of products due to violation of storage technology, or transportation, or production of products from low-quality raw materials;

3) disruption of delivery terms due to: a) an increase in the order fulfillment time due to an increase in the technological time of order fulfillment or an increase in equipment downtime; b) an increase in delivery time, non-optimality of transport routes or a decrease in the speed of vehicles;

4) an increase in general logistics costs associated with an increase in transport tariffs or the cost of logistics or intermediary services, or an increase in raw material prices.

Moreover, failures (failures) in the operation of supply chains can be caused by various external events that are beyond the control of the firm, such as natural disasters (for example, the COVID-19 pandemic) or wars, and internal events (for example, the absence of unforeseen circumstances or ineffective management), which are under the control of the company. Therefore, supply chain reliability is influenced by three different capabilities:

- absorbing (absorption);
- adaptive;
- restorative[90].

They are associated with certain periods of supply chain activity:

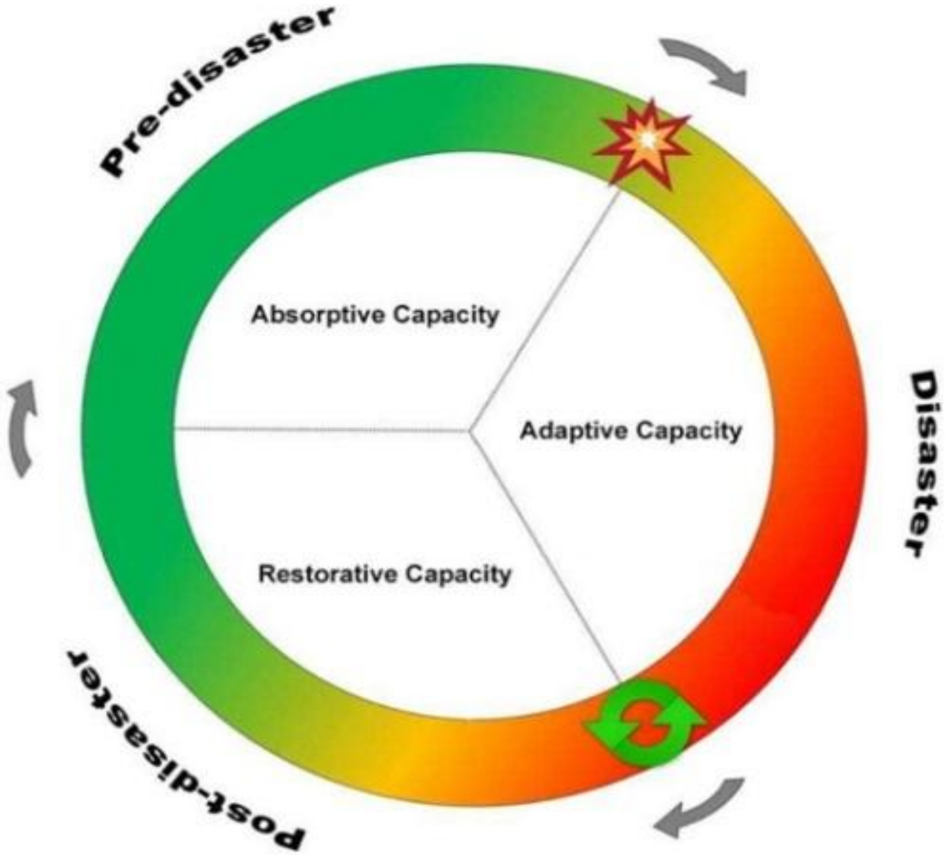
– before the onset of adverse circumstances (crisis event);

– during a crisis event and destruction of the supply chain;

- during its further restoration.

In fig. 1.20 presents the relationship between the three periods, abilities and opportunities necessary to increase reliability, and in the table. 1.9 between capabilities, factors and assessments of supply chain reliability.

[90]Hosseini S., Barker K. Modeling infrastructure resilience using Bayesian networks: A case study of inland waterway ports, Computers & Industrial Engineering, Volume 93, 2016, 252-266.



Rice. 1.20 Cyclescrisis events and the state of reliability potential
Source:Habibi F., Chakrabortty RK, A Abbasi A., Evaluating supply chain network resilience considering disruption propagation, Computers & Industrial Engineering, Volume 183, 2023, 109531.

Table 1.9 – Capabilities, factors and assessments of supply chain reliability

Ability	Factors	Rating	The authors
Absorbingability	Stability	The period of time during which the supply chain performs its tasks under unfavorable circumstances	Chen X., Xi Z., Jing P. A unified framework for evaluating supply chain reliability and resilience IEEE Transactions on Reliability, 66 (4), 2017, 1144-1156.

Ability	Factors	Rating	The authors
	Readiness	Tolerable degree of performance degradation in case of failure	Li Y., Zobel CW, Seref O., Chatfield D.Network characteristics and supply chain resilience under conditions of risk propagation. International Journal of Production Economics, 223, 2020, Article 107529
Adaptive ability	Speed of response	The length of time during which the performance of the system is reduced	Cheng Y., Elsayed EA, Huang Z. Systems resilience assessments: A review, framework and metrics International Journal of Production Research, 1-28, 2021,10.1080/00207543.2021.1971789
	Persistence	The maximum possible decrease in system performance	Li Y., Zobel CW, Seref O., Chatfield D.Network characteristics and supply chain resilience under conditions of risk propagation. International Journal of Production Economics, 223, 2020, Article 107529
	Ingenuity	The interval between the end of the destruction effect and the	Cheng Y., Elsayed EA, Huang Z. Systems resilience assessments: A review, framework and metrics International Journal of Production Research, 1-28,

Ability	Factors	Rating	The authors
		beginning of the recovery process	2021,10.1080/00207543.2021.1971789
Regenerative capacity	Recovery time	Recovery time	Behzadi G., O'Sullivan MJ, Olsen TL On metrics for supply chain resilience European Journal of Operational Research, 287 (1), 2020, 145-158.
	Degree restoration	The maximum possible return to a normal state	Sawik TA portfolio approach to supply chain disruption management International Journal of Production Research, 55 (7). 2017, 1970-1991.

Source: compiled on the basis of scientific sources

To evaluate these three reliability capabilities, scientists identify several factors that can be brokenabsorptive, adaptive and regenerative capacity of the supply chain[91]. Improving these factors can increase the appropriate capabilities of the supply chain, leading to an increase in its overall reliability.

[91] Abbasi M.,Varga L.Steering supply chains from a complex systems perspective,European Journal of Management Studies, 2022, Vol. 27 No. 1, pp. 5-38.https://doi.org/10.1108/EJMS-04-2021-0030;Corrales-Estrada AM, Gómez-Santos LL, Bernal-Torres CA, Rodriguez-López JE Sustainability and Resilience Organizational Capabilities to Enhance Business Continuity Management: A Literature Review. Sustainability 2021, 13, 8196. https://doi.org/10.3390/su13158196; Emrouznejad A., Abbasi S., Sıcakyüz S., Supply chain risk management: A content analysis-based review of existing and emerging topics, Supply Chain Analytics, Volume 3, 2023, 100031; Espino-Rodríguez TF, Gebril Taha M. Absorptive Capacity and Supply Chain Integration and Their Impact on Hotel Service Performance. Adm. Sci. 2023, 13, 247.https://doi.org/10.3390/admsci13120247;Habibi F., Chakrabortty RK, A Abbasi A., Evaluating supply chain network resilience considering disruption propagation, Computers & Industrial Engineering, Volume 183, 2023, 109531.;Hosseini S., Barker K. Modeling infrastructure resilience using Bayesian networks: A case study of inland waterway ports, Computers & Industrial Engineering, Volume 93, 2016, 252-266.; Rinaldi M., Murino T., Gebennini E., Morea D., Bottani E. A literature review on quantitative models for supply chain risk management: Can they be applied to pandemic disruptions? Comput Ind Eng. 2022 Aug;170:108329. doi:

However, the main factors that determine the directions of research on the reliability of supply chains remain[92]:

1. Growing competition in the logistics services market, which increases both the complexity of logistics systems and the responsibility for maintaining a given level of logistics service.

2. Efficiency, which according to the concept of sustainable development tends to focus when characterizing key operations and main partners in the supply chain not only on economic indicators, but also on a set of indicators of environmental and social efficiency (energy efficiency, pollutants, health and safety of their employees professional and career growth, child labor, support of initiatives of local communities, etc.).

3. Establishing trust among various stakeholder groups in the performance of the supply chain, which can potentially increase its reliability and, in turn, protect the existence of the firm with a constant flow of income.

Table 1.10 shows how the factors of increasing the reliability of the supply chain affect its competitiveness on the goods (services) market.

Table 1.10 – Relationship of reliability with competitive advantage

The results	Competitive advantage
Risk avoidance based on objective factors: - effective judgment about the availability and quality of natural resources in the supply chainanh;	Preserving brand value (e.g. image) and exploiting delays, distortions and disruptions affecting competitors.

10.1016/j.cie.2022.108329.; Velenturf A, Purnell R. Principles for a sustainable circular economy, Sustainable Production and Consumption, Volume 27, 2021, 1437-1457.

[92]Zagurskiy O., Pivtorak M., Bondariev S., Demin O., Kolosok I. Methods of reliability management in supply chain. Proceedings of the 22nd International Scientific Conference Engineering for Rural Development 24-26.05.2023 Jelgava, LATVIA. 76-84. url. https://www.tf.llu.lv/conference/proceedings2023/

- objective assessment of partners' activities; - integrated thinking and intuition.	
Efficiency, based on objective factors: - awareness of all supply chain participants; - deferred costs; - a richer set of ideas and options, which leads to cheaper solutions;	Competing with lower costs or pursuing an aggressive growth strategy.
Trust, based on the driving forces of perception: - efforts to give stakeholders a sense of the importance of their contribution to the process; - procedural legitimacy supported by independent parties; - personal legitimacy.	Ensuring a continuous flow of income by increasing the willingness of the parties to pay or mitigating the punishment of the interested parties

Source: compiled on the basis of literary sources

Accordingly, modern supply chain integration considers three interrelated aspects, namely: customer integration; internal integration and suppliers and integration of both customers and suppliers (i.e. external integration) that have corresponding effects on its reliability.

When considering an extended supply chain as a single system based on both material and information flows, as well as on contractual relationships, external integration is the degree to which supply, production and distribution processes at several levels are structured, linked one with one and synchronized.

External integration creates relationships among firms in an extended supply chain, thereby influencing their strategic response to competitive challenges, threats, and opportunities.

CHAPTER 2. ECONOMIC AND MATHEMATICAL MODELS OF SUPPLY CHAIN RELIABILITY

2.1. Development of a model representation of supply chain reliability

As we noted in the previous section, reliability theory, methods of planning logistics business processes based on operations research, and risk management theory are the basis of methods for assessing and improving the reliability of supply chains.

According to them, there are many methods of calculating the reliability of supply chains. The main ones are:

– methods based on the application of probability theory theorems;

– logical-probabilistic methods;

– topological methods;

– methods based on the theory of Markov processes;

– methods of integral equations;

– methods of statistical modeling

The ways of describing the functioning of complex systems in the sense of their reliability are:

– structural diagram;

– functions of logic algebra;

– graph of states;

– differential and algebraic equations;

– integral equations, etc.

Among the methods listed above for describing the functioning of complex systems, the structural schemes and functions of the algebra of logic have become the most widespread due to their relative simplicity.

Regarding the classification of models for evaluating and ensuring the reliability of operations in supply chains, it should be noted that over the past 10 years, a sufficient number of works have appeared devoted to various aspects of the problem of reliability in logistics and supply chain management[1]. The most important achievements of these works are:

1) transition from qualitative expert assessments of reliability to quantitative indicators;

2) selection of the main methods of increasing the reliability of supply chains, mainly due to various types of redundancy;

3) development of supply chain reliability optimization models.

A number of works are also devoted to the analysis of supply chains from the standpoint of structural and functional reliability[2], in which the approach to

---

[1]Amirian S., Amiri M., Taghavifard M.T. The Emergence of a Sustainable and Reliable Supply Chain Paradigm in Supply Chain Network Design, Complexity, vol. 2022, Article ID 9415465,https://doi.org/10.1155/2022/9415465;Durach CF,Wieland A., Machuca JADAntecedents and dimensions of supply chain robustness: a systematic literature review,International Journal of Physical Distribution & Logistics Management, 2015, Vol. 45 No. 1/2, 118-137.https://doi.org/10.1108/IJPDLM-05-2013-0133; Kain R., Verma A. Logistics Management in Supply Chain – An Overview, Materials Today: Proceedings, Volume 5, Issue 2, Part 1, 2018, 3811-3816;Mishra R.,Singh RKA systematic literature review on supply chain resilience in SMEs: learnings from the COVID-19 pandemic,International Journal of Quality & Reliability Management, 2023, Vol. 40 No. 5, 1172-1202.https://doi.org/10.1108/IJQRM-03-2022-0108.; Ozkan O., Kilic S. A Monte Carlo Simulation for Reliability Estimation of Logistics and Supply Chain Networks, IFAC-PapersOnLine, Volume 52, Issue 13, 2019, 2080-2085.; Skowron-Grabowska B, Wincewicz-Bosy M, Dymyt M, Sadowski A, Dymyt T, Wąsowska K. Healthcare Supply Chain Reliability: The Case of Medical Air Transport. Int J Environ Res Public Health. 2022 Apr 4;19(7):4336. doi: 10.3390/ijerph19074336. PMID: 35410017; PMCID: PMC8998864.; Tiwari S., Sharma P., Choi T.-M., Lim A., Blockchain and third-party logistics for global supply chain operations: Stakeholders' perspectives and decision roadmap, Transportation Research Part E: Logistics and Transportation Review, Volume 170 , 2023, 103012.; Zagurskyi O., Ohiienko M., Pokusa T., Zagurska S., Pokusa F., Titova L., Rogovskii I. Study of efficiency of transport processes of supply chains management under uncertainty. Monograph. Opole: The Academy of Management and Administration in Opole, 2020; 162.; Zagurskyi O., Pokusa T., Duczmal M., Ohiienko M., Zagurska S., Titova L., Rogovskii I. Ohiienko A. Supply chain logistics service system: methods and models of its optimization. Monograph. Opole: The Academy of Management and Administration in Opole, 2022; 192.

[2]Ahmed HF, Hosseinian-Far A., Khandan R., Sarwar D., E-Fatima K. Knowledge Sharing in the Supply Chain Networks: A Perspective of Supply Chain Complexity Drivers. Logistics 2022, 6, 66. https://doi.org/10.3390/logistics6030066; Dolgui A., Ivanov D. Exploring supply chain structural dynamics: New disruptive technologies and disruption risks, International Journal of Production Economics, Volume 229, 2020, 107886;Kumar D.,Sony G.,Kazancoglu Y.andRathore APSOn the nature of supply chain reliability: models, solution approaches and agenda for future research,International Journal of Quality & Reliability Management, 2023, Vol. ahead-of-print No. ahead-of-print.https://doi.org/10.1108/IJQRM-08-2022-0256; Zhang M., Chen J., Chang SH., An adaptive simulation analysis of reliability model for the system of supply chain based on partial differential equations, Alexandria Engineering Journal, Volume 59, Issue 4, 2020, 2401-2407.;Raj A., Mukherjee AA, de Sousa Jabbour ABL, Srivastava SK Supply chain management during and post-COVID-19 pandemic: Mitigation strategies and practical lessons learned. J Bus Res. 2022 Mar;142:1125-1139. doi: 10.1016/j.jbusres.2022.01.037.

assessing the reliability of supply chains, based on the theory of technical system reliability, became widespread.

Part of the conceptual apparatus and a number of reliability assessment models and methods are used in these works. Prerequisites for the application of the theory of reliability of technical systems in logistics existed earlier, but works on the implementation of reliability calculations appeared relatively recently.

The issues of improving the planning methods of various logistics business processes are no less studied. It is enough to mention such well-known problems as the calculation of the lot size and the selection of suppliers (Inventory Lot-Sizing Problem with Supplier Selection) or the routing of vehicles (Vehicle Routing Problem – VRP). As a rule, the mathematical formulation of these tasks is complicated by additional restrictions associated, for example, with the uncertainty of consumption or the need to take into account hourly windows during route planning. An increase in the degree of uncertainty in the planning of logistics processes leads to the need to create and optimize complex dynamic and stochastic programming models or use simulation modeling methods[3].

In recent years, publications devoted to the problem of risk management and security of supply chains have also appeared[4]. The analysis of which makes it possible to classify models for ensuring the reliability of operations in supply chains (Fig. 2.1).

---

[3]Amirian S., Amiri M., Taghavifard M.T. The Emergence of a Sustainable and Reliable Supply Chain Paradigm in Supply Chain Network Design, Complexity, vol. 2022, Article ID 9415465, 29.https://doi.org/10.1155/2022/9415465.; Zagurskiy O., Savchenko L., Makhmudov I., Matsiuk V. Assessment of socio-ecological efficiency of transport and logistics activity. Proceedings of 21st International Scientific Conference Engineering for Rural Development 25-27.05.2022 Jelgava, LATVIA. 543-550

[4]Gurtu A., Johny J. Supply Chain Risk Management: Literature Review. Risks, 2021, 9, 16.https://doi.org/10.3390/risks9010016;Lohner-Moeslang K. New challenges in the area of supply chain risk management: Unpredictable events and their effects, Journal of Applied Leadership and Management, ISSN 2194-9522, Hochschule Kempten - University of Applied Sciences, Professional School of Business & Technology, Kempten , 2022, Vol. 10, Iss. 60-84.https://journal-alm.org/article/view/23357/; Rinaldi M., Murino T., Gebennini E, Morea D., Bottani E. A literature review on quantitative models for supply chain risk management: Can they be applied to pandemic disruptions?, Computers & Industrial Engineering, Volume 170, 2022, 108329; Vanany I., Zailani S., Pujawan N. Supply Chain Risk Management: Literature Review and Future Research.. IJISSCM. 2009. 2. 16-33.; Vega de la Cruz, Leudis O., Pérez-Pravia, Milagros C. Gestión integrada de risgos de la seguridad de las cadenas de sécurités con enfoque al servicio al cliente. Ingeniería y competitividad, 2022. 24(2), e202111197.; Epub May 26, 2022.https://doi.org/10.25100/iyc.v24i2.11197: Wiengarten F., Humphreys P., Gimenez S., McIvor R., Risk, risk management practices, and the success of supply chain integration, International Journal of Production Economics, Volume 171, Part 3, 2016, 361-370.

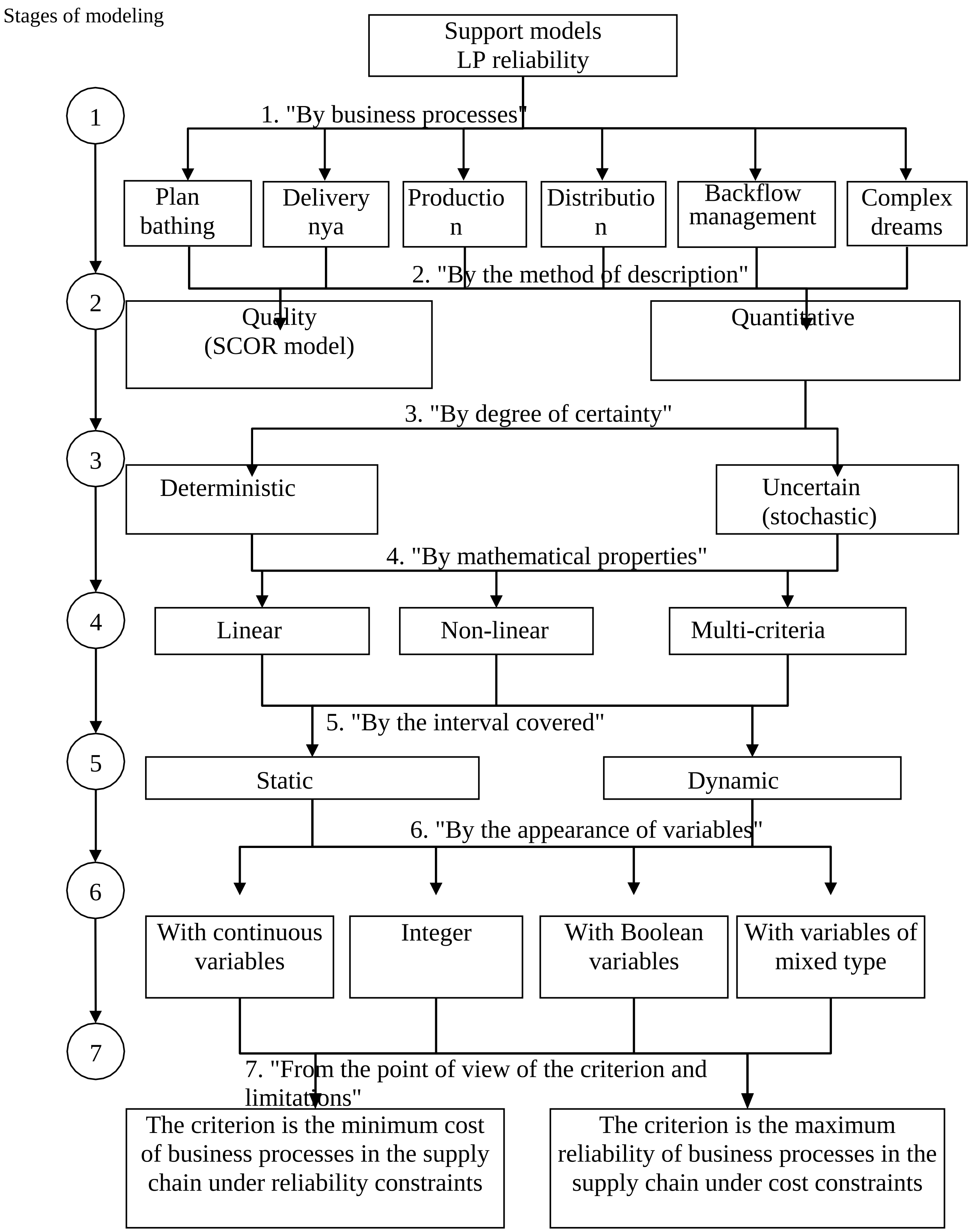


Fig. 2.1 – Classification of models for ensuring the reliability of operations in supply chains and its relationship with the modeling process

Source:compiled by the authors

It is conducted according to various criteria, which complicates both the process of choosing an existing model and the process of creating a new one. Accordingly, the process of creating a new model for assessing the reliability of operations in supply chains is a hierarchical process and includes the following stages.

Stage 1. The business processes for which the model is being built are determined. Thus, the model can be built both for a separate business process (planning, supply, production, distribution, reverse flow management, etc.) and a complex model (covering several business processes).

Stage 2. The method of describing the business process is chosen: qualitative or quantitative. In the first case, a SCOR model of the supply chain or a functional model of a separate business process is built, and in the other - a mathematical model (for example, a linear programming model).

Stages 3 - 6. Mathematical properties of quantitative models are specified, which can be:

- according to the degree of certainty: deterministic and indeterminate (stochastic) models;

- by the time interval covered: static (one-period) and dynamic (multi-period) models;

- by mathematical properties, type of objective function and constraints: linear objective function and/or constraints, nonlinear objective function and/or constraints, multi-criteria models;

- by type of variables: with continuous variables, integers, Boolean, mixed type.

Stage 7. Criteria and limitations of the reliability model are selected. The analysis of scientific works shows that two options are most often used:

- criterion – minimum costs for business processes in the supply chain with restrictions on reliability;

- criterion - the maximum reliability of business processes in the supply chain under cost restrictions.

The hierarchical classification of models for evaluating and ensuring the reliability of operations in supply chains, presented in Fig. 2.1, is related to their mathematical properties and can be the conceptual basis of the modeling process, that is, the procedure for creating a new model for evaluating and ensuring the reliability of operations in supply chains. From the point of view of research tasks, the most interesting is the systematization and classification of models for ensuring the reliability of operations in supply chains according to the criterion of assignment to a certain logistic business process, which is the object of mathematical modeling.

Tables 2.1-2.6 present a summary of information on the developed models and methods for ensuring the reliability of operations in supply chains in accordance with the stages of supply chain management, which does not claim to cover all existing models, but allows a better understanding of the severity of the problem assessment and ensuring the reliability of operations in supply chains.

Table 2.1 Models and methods of ensuring operational reliability in supply chain planning

Models and methods	Source	Authors or developers
	Supply chain planning	
SCOR model	http://www.apics.org	Supply Chain Council
Production and transport warehouse model	ShapiroJ. Modeling the Supply Chain] Cengage Learning, 2006. 618.	ShapiroJ.

PILOT optimization model (function of fixed and variable production and transport costs depending on supply, capacity and destination)	Cohen, MA and Moon, S. “Impact of production scale economics, manufacturing complexity, and transportation costs on supply chain facility networks,” Journal of Manufacturing and Operations Management, 1990. Vol. 3, 269-292.	Cohen MA Moon S.
Optimization models of the network structure of the supply chain	http://www.oracle.co m	Oracle Corporation
	Supply planning	
Deterministic model for determining the level of basic stocks	Ishii K, Takahashi K., Muramatsu R. Integrated production, inventory and distribution systems, International Journal of Production Research, 1988. 26:3, 473-482.	Ishii K, Takahashi K., Muramatsu R.
A deterministic, mixed-integer, nonlinear mathematical model built on economic order quantity (EOQ) methods	Cohen, MA and Lee, HL Resource Deployment Analysis of Global Manufacturing and Distribution Networks. Journal of Manufacturing and Operations Management, 1989. 2, 81-104.	Cohen MA, Lee HL
Methods of calculating the need for spare parts based on the theory of recovery processes, including the method of	Ghodrati V. Reliability and Operating Environment Based Spare Parts Planning Luleå University of Technology Division of Operation and	Ghodrati V.

inventory management based on the analysis of the operational reliability of technical systems	Maintenance Engineering, 2005. 21Kubon M., Kaczmar I., Findura P. Reliability of technical systems and the methodology for calculating MTBF using Flexsim computer simulation. E3S Web of Conferences. 2019. 132. 01012.	Kubon M., Kaczmar I., Findura P.
Supplier selection and lot size optimization models, including a dynamic model for supplier selection and lot size optimization with warehouse space and budget constraints	Mazdeh M., Emadikhiav M., Parsa I., A heuristic to solve the dynamic lot sizing problem with supplier selection and quantity discounts, Computers & Industrial Engineering, Volume 85, 2015, 33-43; Chirawat W., Tarathorn K, Vichai R. Inventory Lot-Sizing Problem with Supplier Selection under Storage Space and Budget Constraints // IJCSI International Journal of Computer Science Issues, Vol. 8, Issue 2, March 2011. 250-255.	Mazdeh M, Emadikhiav M. Parsa I., Chirawat W., Tarathorn K, Vichai R.
A stochastic model of the supplier selection and delivery lot size optimization task under	Hahn G., Kuhn H. Value-based performance and risk management in supply chains: A robust optimization approach. International Journal of Production	Hahn G., Kuhn H.

changing demand conditions	Economics. 2011. 139. 135-144. 10.1016/j.ijpe.2011.04.002.	
Production planning		
Dynamic models of the problem of allocation of resources for several periods	Raghavendar K., Batra I., Malik A. A robust resource allocation model for optimizing data skew and consumption rate in cloud-based IoT environments, Decision Analytics Journal, Volume 7, 2023, 100200	Raghavendar K., Batra I., Malik A.
Stochastic models of the problem of resource allocation for several periods	ShapiroJ. Modeling the Supply Chain] Cengage Learning, 2006. 618.	ShapiroJ.
Distribution planning		
A dynamic model of purchasing and selling goods in conditions of changing demand	Gowrisankaran G., Rysman M. Dynamics of Consumer Demand for New Durable Goods. Journal of Political Economy, vol. 120, no. 6, 2012. 1173-219. https://doi.org/10.1086/669540. Laari S.,Lorentz H.,Jonsson P.,Lindau R.Procurement's role in resolving demand–supply imbalances: an information processing theory perspective,International Journal of Operations & Production	Gowrisankaran G., Rysman M. Laari S., Lorentz H., Jonsson P. Lindau R.

	Management, 2023. Vol. 43 No. 13, 68-100.	
A dynamic model of a multi-nomenclature task on the strategy of purchasing and selling goods in conditions of variable demand	Aydin R., Badurdeen F. Sustainable product line design considering a multi-lifecycle approach, Resources, Conservation and Recycling, Volume 149, 2019, 727-737. Knight L., Tate W., Carnovale S., Di Mauro S., Bals L., Caniato F., Gualandris J., Johnsen T., Matopoulos A., Meehan J., Miemczyk J. Future business and the role of purchasing and supply management: Opportunities for 'business-not-as-usual' PSM research, Journal of Purchasing and Supply Management, Volume 28, Issue 1, 2022, 100753	Aydin R., Badurdeen F. Knight L., Tate W., Carnovale S., Di Mauro S., Bals L., Caniato F., Gualandris J., Johnsen T., Matopoulos A., Meehan J., Miemczyk J.
A dynamic model of alternative designs with multiple structural ones to meet changing supply and demand conditions	Caniato F., Moretto A., Caridi, M. Dynamic capabilities for fashion-luxury supply chain innovation. International Journal of Retail and Distribution Management, 2013. 41(11/12), 940–960.	Caniato F., Moretto A., Caridi M.
A stochastic model of a multi-nomenclature task on the strategy of	Islam SSM, Hoque A., Hamzah N. Single-supplier single-manufacturer multi-retailer	Islam SSM, Hoque A., Hamzah N.

purchasing and selling goods in conditions of changing demand.	consignment policy for retailers' generalized demand distributions, International Journal of Production Economics, Vol. 2017. 184, 2017, 157-167	

Source: compiled on the basis of literary sources

Table 2.2 – Models and methods of ensuring the reliability of supply operations

Models and methods	Source	Authors or developers
The model functionally structural reliability of the supply chain	Zhang M., Chen J., Chang SH An adaptive simulation analysis of reliability model for the system of supply chain based on partial differential equations, Alexandria Engineering Journal, Volume 59, Issue 4, 2020, 2401-2407	Zhang M., Chen J., Chang SH
A stochastic model of supply chain failures using a Fat Tail distribution	Rodriguez-Aguilar R., Marmolejo-Saucedo JA Structural Dynamics and disruption events in Supply Chains using Fat Tail Distributions, IFAC-PapersOnLine, Volume 52, Issue 13, 2019, 2686-2691	Rodriguez-Aguilar R., Marmolejo-Saucedo JA
The model for calculating	Zagurskiy O., Pivtorak M.,	Zagurskiy O.,

the reliability of supplies, which corresponds to the exponential and normal laws of the distribution of the intensity of failures	Bondariev S., Demin O., Kolosok I. Methods of reliability management in supply chain. Proceedings of the 22nd International Scientific Conference Engineering for Rural Development 24-26.05.2023 Jelgava, LATVIA. 76-84. url. https://www.tf.llu.lv/conference/proceedings2023	Pivtorak M., Bondariev S., Demin O., Kolosok I.
The model of the task of determining the optimal supply plan with considering reliability	Tadayonrad Y., Ndiaye AB A new key performance indicator model for demand forecasting in inventory management considering supply chain reliability and seasonality, Supply Chain Analytics, Volume 3, 2023, 100026	Tadayonrad Y., Ndiaye AB

Source: compiled on the basis of literary sources

Table 2.3 – Models and methods of ensuring the reliability of production operations

Models and methods	Source	Authors or developers
Analytical model for determining the optimal	Lee HL, Feitzinger E.: Product configuration and postponement for supply chain efficiency. In:	Lee HL Feitzinger E.

stage of product production	Proceedings of the 1995 4th Industrial Engineering Research Conference, Nashville – USA. 1995. 43-48.	
A model based on a set of methods and tools that reflect a changing environment (Lean culture of thinking)	García-Reyes N., Avilés-González J., Avilés-Sacoto SV A Model to Become a Supply Chain 4.0 Based on a Digital Maturity Perspective, Procedia Computer Science, Volume 200, 2022, 1058-1067	García-Reyes N., Avilés-González J., Avilés-Sacoto SV

Source: compiled on the basis of literary sources

Table 2.4 – Models and methods of ensuring the reliability of distribution operations

Models and methods	Source	Authors or developers
Buyer-supplier relationship model "relationship matrix"	Christy DP, Grout JR Safeguarding supply chain relationships, International Journal of Production Economics, Volume 36, Issue 3, 1994, 233-242.	Christy DP, Grout JR
Models for evaluating the effects of different supply chain strategies on demand expansion	Towill DR Supply Chain Dynamics. International Journal of Computer Integrated Manufacturing, 1991. 4, 197-208.	Towill DR

A model for improving the reliability of transport and terminal operations in supply chains	Li D., Jiao J., Wang S, Zhou G. Supply Chain Resilience from the Maritime Transportation Perspective: A Bibliometric Analysis and Research Directions, Fundamental Research, 2023, https://doi.org/10.1016/j.fmre.2023.04.003	Li D., Jiao J., Wang S, Zhou G.

Source: compiled on the basis of literary sources

Table 2.5 – Models and methods for ensuring the reliability of operations in the management of reverse flows

dels and methods	Source	Authors or developers
The model of optimization of return flows based on the criterion "costs to restore the consumer value of the product"	Atabaki MS, Mohammadi M., Naderi V. New robust optimization models for closed-loop supply chain of durable products: Towards a circular economy, Computers & Industrial Engineering, Volume 146, 2020, 106520, ISSN 0360-8352, https://doi.org/10.1016/j.cie.2020.106520.	Atabaki MS, Mohammadi M., Naderi V.

Source: compiled on the basis of literary sources

Table 2.6 – Complex models and methods of ensuring the reliability of operations in supply chains

dels and methods	Source	Authors or developers
A model of multiple structural designs for matching supply and demand	Ruel S., El Baz J., Ivanov D. et al. Supply chain viability: conceptualization, measurement, and nomological validation. Ann Oper Res 2021. https://doi.org/10.1007/s10479-021-03974-9	Ruel S., El Baz J., Ivanov D.
SCOR model	http://www.apics.org	Supply Chain Council
SCOR model with special attention to supply chain sustainability	Ntabe EN, LeBel L., Munson AD, Santa-Eulalia LA A systematic literature review of the supply chain operations reference (SCOR) model application with special attention to environmental issues, International Journal of Production Economics, Volume 169, 2015, 310-332	Ntabe EN, LeBel L., Munson AD, Santa Eulalia LA
SSCM model	Reefke N., Sundaram D. Sustainable supply chain management: Decision models for transformation and maturity, Decision Support Systems, Volume 113, 2018, 56-72.	Reefke N., Sundaram D.

Mixed Integer Programming Model, GSCM	ArntzenBC,BrownGGHarrisonTP,. TraftonL. L Global Supply Chain Management at Digital Equipment Corporation. Interfaces 1995. 25(1):69-93.	ArntzenBC, BrownGG HarrisonTP,TraftonL. L
Process model of formation of reliable supply chains	Beamon B. M, Supply chain design and analysis:: Models and methods, International Journal of Production Economics, Volume 55, Issue 3, 1998, 281-294.	Beamon BM

Source: compiled on the basis of literary sources

The analysis of the information presented in Tables 2.1-2.6 shows that ensuring the reliability of individual business processes has been a concern of scientists for a long time, as evidenced by the large number of developed models. At the same time, it is noteworthy that the largest number of reliability models and methods relate to the "planning" business process, while certain aspects of this problem (in particular, those related to production, distribution and backflow management) are not yet sufficiently developed.

First, complex models for assessment and assurance of reliability are not sufficiently developed, that is, models covering several related business processes. The reason, in our opinion, is that complex models are much more complex in the mathematical aspect. Therefore, in most cases, complex models for ensuring the reliability of supply chains are descriptive models, for example, the SCOR process model, or the model of multiple structural designs. At the same time, interesting quantitative models have appeared in recent years, for example,SSCM-mdress[5].

[5]Reefke N., Sundaram D. Sustainable supply chain management: Decision models for transformation and maturity, Decision Support Systems, Volume 113, 2018, 56-72.

Secondly, the search for return flow management models based on the "reliability" criterion gave practically no results[6]. It only partially meets the specified requirements because it is based on an economic criterion, not reliability.

Thirdly, the planning models of individual business processes are also constantly developing and supplemented by new developments. The largest number of scientific works is devoted to the problems of production scheduling, vehicle routing, supplier selection, and optimization of the supply lot size (see Table 2.1).

The interest of scientists in these problems is caused by their mathematical complexity and the need to take into account a large number of constraints, including probabilistic ones, for example, related to demand uncertainty, changes in resource prices or time constraints (supply windows) for vehicles. But even here, individual issues have not been sufficiently investigated. In particular, the problem and methods of calculating the need for spare parts based on the theory of recovery processes or the problem of selecting suppliers and optimizing the size of the supply lot.

2.2 Formation of supply chain reliability models

Mathematical modeling is the basis of studying the functioning of complex systems in the sense of their reliability. At the same time, researchers have significant difficulties in connection with the specifics of the problems to be solved (random nature of phenomena, multicriteria, high dimensionality of equations, multivariateness and the need to ensure high accuracy). Therefore, the analysis of the application of mathematical models and methods for evaluating and improving the reliability of supply chains, in our opinion, should begin with

[6]Atabaki MS, Mohammadi M., Naderi V. New robust optimization models for closed-loop supply chain of durable products: Towards a circular economy, Computers & Industrial Engineering, Volume 146, 2020, 106520, ISSN 0360-8352, ttps://doi.org/10.1016/j.cie. 2020.106520.

the consideration of the main properties of the supply chains themselves and methods of ensuring their reliability.

By analogy with technical systems, the main properties of supply chains are reliability, economy and safety (Figure 2.2).

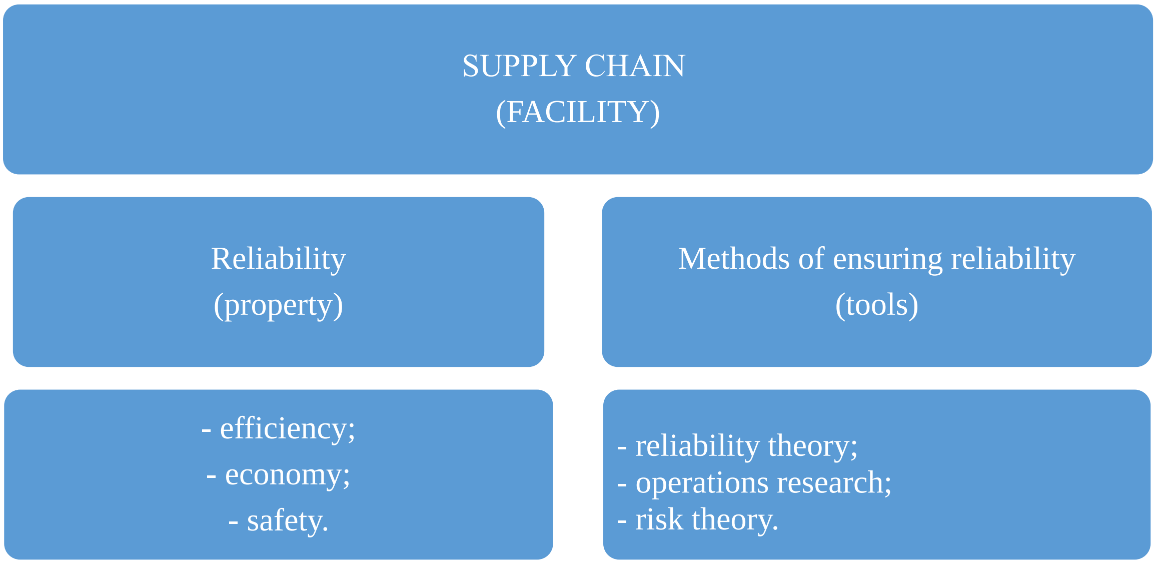


Fig. 2.2 Main properties and methods of increasing the reliability of the supply chain

Source: compiled by the authors

According to him, all methods of increasing the reliability of the supply chain should be considered from the point of view of three approaches:

1. Technical, based on the theory of reliability of technical systems, in which circuit elements are connected in series, in parallel and combined with various types of active or passive redundancy. The main objects here are: reliability criteria of technical systems of various purposes; reliability analysis methods in the process of designing and operating technical systems; methods of synthesis of technical systems; ways of ensuring and improving the reliability of equipment; scientific methods of operating equipment that ensure its high reliability and others.

According to this approach, knowledge of the reliability of each system component is necessary to calculate the reliability of the entire network.To calculate reliability, you need to design the structure of the supply chain system in the form of a structural diagram of the reliability of its elements[7]. And since the supply chain consists of different elements, it can be represented as a system. Therefore, the problem of allocation of reserves (inventories) can be used to assess the reliability of the supply chain.

2. Economic, which is built on the "ideal" order model or the "supply and demand" model. It provides an assessment of the reliability of supply chains based on the optimization of procurement costs, logistics, breach of contractual obligations (penalties, fines, etc.) or indicators of profit and profitability of business processes in supply chains. In this sense, the reliability of the supply chain is its ability to ensure the value of the economic indicators of its functioning within the limits that guarantee the system timely achievement of its goals with minimal expenditure of material, labor and other resources or with the maximum possible economic effect in the planned time interval. That is, the reliability of supply chains should be evaluated by a set of parameters, the list of which may change depending on the operating conditions of the chain. Usually, the economic approach to increasing the reliability of supply chains is based on methods and mathematical models of planning logistics business processes under conditions of uncertainty.

According to this approach, the reliability of the supply chain can be defined as the probability that the planned (initial) capacity of the chain components will be able to respond effectively to fluctuations in demand.In this regard, S. Hagshpil recognizes the possibility that a supply chain with a certain

---

[7] Ahmed S., Akbar M., Ullah R. et al. ARCUN: analytical approach towards reliability with cooperation for underwater WSNs, Procedia Computer Science, 2015, vol. 52, 576–583.:Bueno-Solano A., edillo-Campos MG, Velarde Cantú JM Reliability of the supply chain: method of self-assessment as a first step to building resilient systems, International Journal of Combinatorial Optimization Problems and Informatics, 2016, vol. 7, no. 1, 3-9.; Nosrati M., Arshadi Khamseh A. Reliability optimization in a four-echelon green closed-loop supply chain network considering stochastic demand and carbon price, Uncertain Supply Chain Management, 2020, vol. 8, no. 3, 457-472.

(given) reliability will not be able to meet potential consumer demand with the risk of supply shortages[8].

3. Safe, which takes into account the dangers that may arise in the supply chain and is based on the theory of risk management. It provides possible options for actions in case of unforeseen circumstances, based on the basic concepts of "just in time", quick response, etc. The security criterion in supply chains is usually analyzed in terms of interactions between system participants and the external environment, the status and assessment of hazard and risk accounting.

According to him, the potential risk of additional supplies indicates a low level of reliability of the supply chain[9]. Supply disruptions, increased demand due to changing seasons, and sudden increases in demand lead to supply-demand imbalances.

In addition, B.M. Biamon proposes to divide all multi-level models of supply chain reliability into four categories according to the nature of the origin of the input data and the purpose of the study:

1) economic models;

2) deterministic analytical models in which the variables are known and specified;

3) stochastic analytical models, in which at least one of the variables is unknown and it is assumed that it will follow a certain probability distribution;

4) simulation models[10].

Let's consider the main ones in more detail.

---

[8]Hagspiel S. Supply Chain Reliability and the Role of Individual Suppliers, EWI Working Paper, Institute of Energy Economics at the University of Cologne (EWI), Köln, 2016.31.; Hagspiel S. Reliability with interdependent suppliers, European Journal of Operational Research, 2018, vol. 268, 1, 161-173.

[9] Wang B., Zhang H., Yuan M., Guo Z., Liang Y. Sustainable refined products supply chain: a reliability assessment for demand - side management in primary distribution processes, Energy Science & Engineering, 2020, vol. 8, no. 4, 1029-1049.

[10]Beamon BM, Supply chain design and analysis:: Models and methods, International Journal of Production Economics, Volume 55, Issue 3, 1998, 281-294.

2.2.1 Formation of economic models of supply chain reliability

The "supply and demand" model

The model is based on the laws of probability theory. In itthe probability distribution of the sum of two random variables z = x + y, in the case when the random variables are independent, is expressed by one of the formulas[11].

$$\int \infty -\infty f(z) = f(x) f(z - x)dx \tag{2.1}$$

or

$$f(z) = \int f(z - y) f(y)dy \tag{2.2}$$

where: f(z) – the density of the distribution of components f1(x) and f2 (y).

When describing the logistics processes of procurement and order management with stochastic consumer demand (y) and supplier supply (x), it is necessary to take into account the difference between these random variables, i.e. z = x – y = x + (– y). In this case, expressions (1) and (2) are transformed into formulas:

$$f(z) = \int f(x) f(x - z)dx = \int f(y - z) f(y)dy \tag{2.3}$$

The corresponding probability of consumer satisfaction (absence of shortage) is determined by the dependence:

$$F(z)=\int f(z)\, dy \tag{2.4}$$

The numerical method of calculating f(z) and F(z) is the most common, but analytical solutions can be obtained for some distribution functions (Fig. 2.3).

[11]Wentzel E. WITH. Probability theory: a monograph. M.: Nauka, 1969. 578

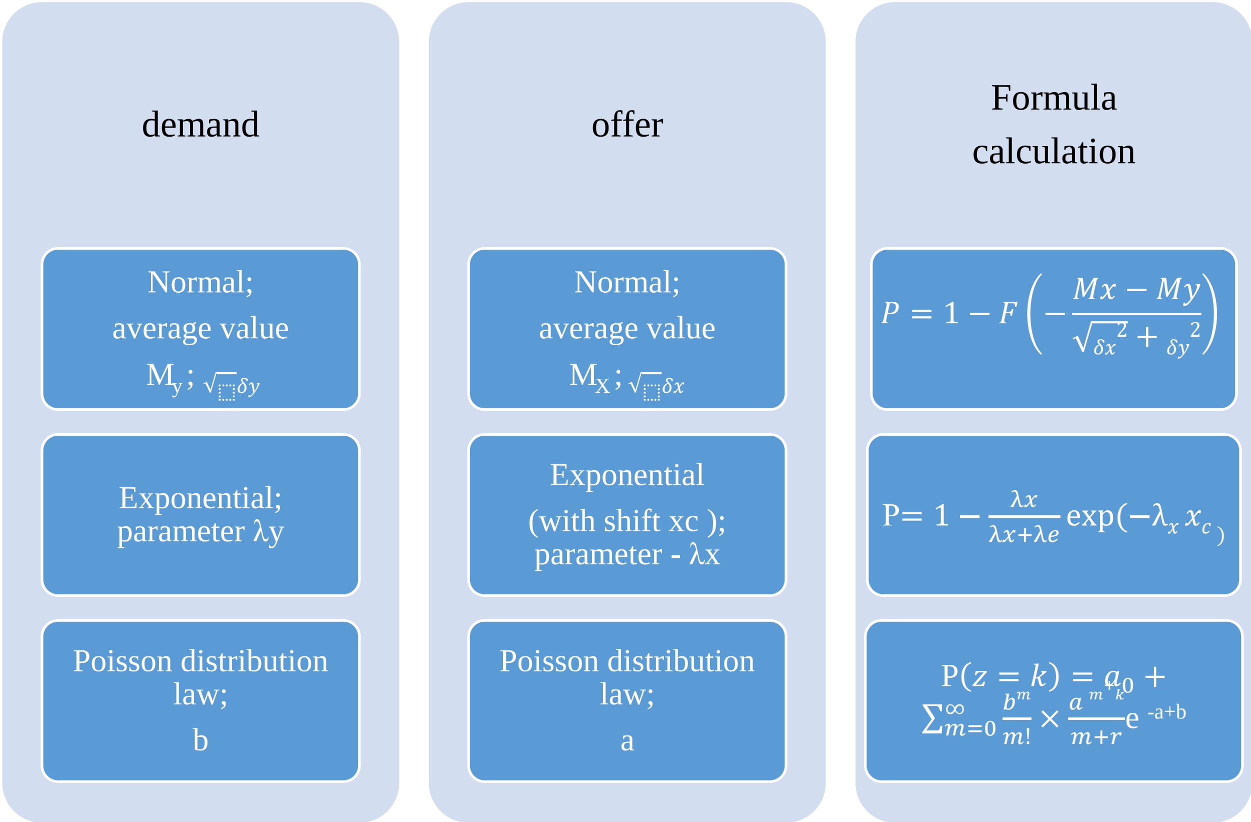


Fig. 2.3 Formulas for calculating the probability of demand satisfaction ("demand and supply" model)

Source: compiled by the authors based on literary sources

Model "determining the ideal order quantity"

The model is based on the well-known static (or one-period) inventory management problem.The most common version of the model can be determined by the formula:

$$C_z = C(s - z) + h \int_0^s (s - z) f(x) dx + p \int_s^{\infty} (x - s) f(x) dx, \qquad (2.5)$$

where: c – the purchase (or production) price of a product unit;

s – order size;

z – initial stock (before order);

h – specific costs associated with the storage of surpluses;

x – a random value of demand for a product with a distribution density;

p – specific losses fromunsatisfied demand.

Under the condition (dCz /ds) = 0, after transformations we find the so-called "critical ratio"

$$F(s) = \frac{p-s}{p+h}, \qquad (2.6)$$

where: F(s) – the cumulative demand distribution function.

From the point of view of assessing the reliability of the supply chain, this model allows you to calculate the probability of an unsold batch of products or the probability of a shortage P(s) = 1 – F(s).

It should be emphasized that the "critical ratio" depends only on the cost parameters. Thus, the order size S will be determined by the distribution function F(s) chosen to approximate the demand.

Table 2.6 shows the formulas for determining S and the results of comparative calculations for some distribution laws.

Table 2.6 – Optimal order size for a one-time purchase with different distribution laws

Law of distribution	Parameters of the law	The optimal order size is S
Normal	x; sx	$F\left(\frac{s-\bar{\bar{x}}}{\sigma}\right) = \frac{p-c}{p+h}$
Exponential	$\lambda = \frac{1}{x}$	$S = \frac{1}{\lambda} ln \frac{p+h}{c+h}$
Weibull*	$m = f(u);\ x_0 = \frac{\bar{\bar{x}}}{b_m};$	$S = x_0 \sqrt[m]{ln \frac{p+h}{c+h}}$
Rayleigh	$M = \frac{\bar{\bar{x}}}{\sqrt{0.5\pi}}$	$S = M\sqrt{2}\, ln \frac{p+h}{c+h}$
Uniform	$a = \bar{\bar{x}}\,; b = \sigma\sqrt{3}$	$S = \frac{p-c}{p+h}(b-a) + a$

*For the Weibull distribution, the parameters m and bm are determined by the gamma function based on the coefficient of variation υ

Source: compiled by the authors based on literary sources

The model according to the criterion of minimum costs

The classic process model of supply chain management based on the criterion of minimum costs with independence of processes has the form

$$S = \sum_{i=1}^{n\Sigma} \sum_{j=1}^{m} S_{ij} \times X_{ij} \rightarrow min, \quad (2.7)$$

for restrictions

$\sum_{j=1}^{m} X_{ij} = 1, \forall i = 1, n$ on the number of processes in the supply chain

$\prod_{i=1}^{n} \sum_{j=1}^{m} P_{ij} \times X_{ij} \geq \beta$on supply chain reliability

where: n is the number of processes in the supply chain;

m = max {ki}n, ki – the number of possible options (strategies) for the implementation of the ith process;

Si,j – costs for the i-th process in the supply chain for the implementation of the j-th strategy;

$\{S_{ij}\}$nm – process cost matrix;

β – the required reliability of the supply chain (probability of failure-free operation of the supply chain);

Pi,j – the probability of failure-free implementation of the jth strategy in the ith process;

{Pij}nm – the probability matrix of fault-free operation;

Xi,j – a binary variable (choice variable) that takes the value 0 or 1

The difficulty of using model (2.7) is the need for statistical studies to obtain objective estimates of the matrix {Pij}nm. At the same time, during the design of the supply chain, it is necessary to solve the task of selecting suppliers (supply process) taking into account the requirements of the end user for the reliability of supplies β. That is, there is a task of standardizing requirements for process reliability. Solving this task is possible under the assumption that the processes are independent, and the failure flows are the simplest. Then the main reliability equation is transformed into the expression (2.8)

$$P(t_\beta) = exp(-\lambda_0 t_\beta) = \beta \quad (2.8)$$

where

$$\lambda_0 = -\frac{ln(\beta)}{t_\beta} \tag{2.9}$$

where: λ_0 – the intensity of supply chain failure flow;

t_β– the value of the risk factor (time, volume, etc.) for the β-level of no-failure.

In the absence of processes with a dominant intensity of failures in the supply chain, it can be assumed

$$\lambda_{ij} = \lambda_0 \omega_{ij} \tag{2.10}$$

where: λi,j – the intensity of failures of the i-th process with the j-th implementation strategy,

ωi,j – the weight coefficient of the contribution of the jth strategy of the ith process to the overall intensity of supply chain failures.

Accordingly, the probability of failure-free implementation of the jth strategy in the ith process is equal to:

$$P_{i,j} = exp(-\lambda_0 \omega_{i,j} t_\beta) = exp[\omega_{i,j}\, ln(\beta)] \tag{2.11}$$

It remains to define the matrix of weighting coefficients. $\{\omega_{i,j}\}_n^m$ of course, the requirement for the reliability of the process should be the higher, the greater the damage caused by the refusal to implement it. Losses here can be measured by process recovery costs, product sales losses, or image losses. They can be estimated due to losses in turnover and tariffs according to the formula:

$$R = Q \cdot d\left[1 - \left(1 - \frac{\delta}{100}\right)\left(1 - \frac{\varepsilon}{100}\right)\right], \tag{2.12}$$

where: Q – turn over of goods;

d – the sale price of the product;

δ, ε – turnover and price losses in %, respectively.

The weighting factors in this case are related to costs in an inversely proportional relationship and are determined by the formula:

$$\omega_{i,j} = \frac{1}{R_{i,j}\sum_{i=1}^{m}\frac{1}{R_{i,j}}}, \tag{2.13}$$

where:$R_{i,j}$ – costs associated with failure to implement the j-th strategy of the i-th process.

Model of optimization of logistics service

The procedure for finding the optimal solution in this model involves choosing (from many possible) values of logistics service indicators that ensure the formation of maximum profit and, accordingly, reliability while observing the established restrictions. Alternative profit values are calculated by subtracting the corresponding values of estimated total costs from the estimated revenue values. Values of revenue and total logistics costs are calculated by adding to the base values of the specified indicators the values of the increase, which are calculated using coefficients dependent on the values of the indicators of the logistics service.

$$TR = TR - TS \tag{2.14}$$

where: TP – the profit value of the supply chain;

TR – value of supply chain revenue;

TC – the value of the total logistics costs of the supply chain.

The value of revenue, taking into account its increase from the level of logistics service, is calculated according to the formula:

$$TR = Rb + \Delta R, \tag{2.15}$$

where: Rb – the value of revenue when implementing a logistics service at the basic level;

ΔR - the total increase in revenue caused by the implementation of a logistics service different from the basic level.

The increase in revenue provided by any value of any of the analyzed logistics service indicators can be calculated as follows:

$$\Delta R\text{ij}(S\text{ij}) = Rb \times (Kr\text{ij}(S\text{ij}) - 1), Kr\text{ij} > 0, \forall \text{i} \in \{1, ..., n\}, \forall \text{J} \in \{1, ..., m\}, \tag{2.16}$$

where: i is the number of the logistics service indicator;

J – the number of the possible value of the logistics service indicator;

ΔR_{ij} – revenue growth provided by the j-th value of the i-th indicator of the logistics service;

S_{ij} – j-th value of the i-th indicator of the logistics service;

Kr_{ij} – a coefficient that reflects the influence of the jth value of the ith indicatorlogistics service for revenue;

n – the number of logistics service indicators;

M – the number of possible values of logistics service indicators.

The total increase in revenue depends on the choice of value for each of the indicators of the logistics service:

$$\Delta R(x_{ij}) = \sum_{i=1}^{n} \sum_{j=1}^{m} \Delta R_{ij} (S_{ij}) \times x_{ij}, x_{ij} \epsilon \{0,1\} \quad (2.17)$$

where: x_{ij} – a Boolean variable reflecting the decision to accept or reject the j-th value of the i-th indicator of the logistics service.

The value of total logistics costs is calculated as follows:

$$TC = TCb + \Delta TC, \quad (2.18)$$

where: TCb is the value of the total logistics costs for the implementation of the logistics service at the basic level;

ΔTC– the total increase in total costs caused by the implementation of the actual logistics service from the base level.

Based on this, the increase in total costs caused by any value of any of the analyzed logistics service indicators can be calculated as follows:

$$\Delta TC_{ij}(S_{ij}) = TCb \times (Kc_{ij}(S_{ij}) - 1), Kc_{ij} > 0, \forall i \in \{1, . . , n\}, \forall J \in \{1, . . , m\}, \quad (2.19)$$

where: ΔTC_{ij} – the increase in total costs caused by the j-th value of the i-th indicator of the logistics service;

Kc_{ij} – a coefficient reflecting the influence of the jth value$i$-th indicatorlogistics service for general expenses.

Moreover, the coefficients Kr_{ij} and Kc_{ij}, which are used in the development of the logistics service optimization model, acquire a value greater than 1, if the value of the logistics service indicator provides an increase in the value of the financial indicator (revenue or total costs), and is in the range from 0 to 1 in the other case.The coefficients of level 1 correspond to the basic values of the logistics service indicators.

The total increase in total costs depends on the choice of value for each of the logistics service indicators:

$$\Delta TC(x_{ij}) = \sum_{i=1}^{n}\sum_{j=1}^{m}\Delta TC_{ij}\,(S_{ij}) \times x_{ij}, x_{ij}\, \epsilon\{0,1\} \quad (2.20)$$

The expression for calculating the value of the maximum allowable increase in total costs has the following form:

$$\Delta TCmax = TCmax - TCb,\ 0 < TCb < TCmax \quad (2.21)$$

where: ΔTC_{max} – the maximum permissible increase in total logistics costs;

TC_{max} – the value of the maximum allowable total logistics costs of the supply chain.

The integration of the components discussed above allows for the development of a mathematical model for optimizing the values of logistics service indicators. The target function of which in expanded form is as follows:

$$TP(x_{ij}) = Rb + \sum_{i=1}^{n}\sum_{j=1}^{m} Rb \times (Kr_{ij}(S_{ij}) - 1) \times x_{ij} -$$

$$- (TCb + \sum_{i=1}^{n}\sum_{j=1}^{m} TCb \times (Kc_{ij}(S_{ij}) - 1) \times x_{ij}) \to \max \quad (2.22)$$

or in an abbreviated and reduced to profit growth form:

$$\Delta TP(x_{ij}) = \sum_{i=1}^{n}\sum_{j=1}^{m} (\Delta R_{ij}(S_{ij}) - \Delta TC_{ij}(S_{ij})) \times 1) \times x_{ij} \to \max \quad (2.23)$$

where: ΔTP – the increase in the profit of the supply chain.

subject to restrictions:

1) limiting the values of variables

$$x\text{ij}\in\{0,1\},\ \text{i}\in\{1, . . . ,n\},\ \text{j}\in\{1, . . . ,m\}; \quad (2.24)$$

2) limiting the choice of only one of the possible values for each indicator of the logistics service

$$\sum_{j=1}^{m} x_{ij} = 1,\ \ \forall i \varepsilon \{1,..., n\} \quad (2.25)$$

3) limiting the growth of total costs

$$\sum_{i=1}^{n}\sum_{j=1}^{m} \Delta TC_{ij}(S_{ij}) \times x_{ij} \le \Delta TC_{\max}, \Delta TC_{\max} \ge 0 \quad (2.26)$$

The developed model is a deterministic linear static model with Boolean variables. If it is necessary to take alternate (staged) consideration of logistics service indicators, the optimization problem can be presented in the form of a dynamic programming model, and the solution is found using recurrent equations. The proposed model allows taking into account the values of a number of logistics service indicators, which distinguishes them from those developed earlier. However, regardless of the type of optimization model, accurate input data, especially those related to actual logistics costs, are required to obtain a reliable solution. The formation of logistics costs takes place in the logistics system, which combines several interconnected subsystems, in connection with which a comprehensive analysis of logistics costs and the mechanism of their formation is necessary in order to develop a model for optimizing the total costs of the supply chain. Such an optimization model can be used independently and as a component of developed models.

2.2.2 Formation of deterministic supply chain reliability models

The accuracy and reliability of supply chain reliability calculations depends on the reliability of the source information, the compliance of the calculation model with real processes and computer technology. Currently, in engineering practice, deterministic calculation models of two types are most common: taking into account the deterministic approach and using analytical dependencies and taking into account the influence of random factors on the course of processes through the use of a probabilistic-statistical approach (Table 2.7).

Table 2.7 – Characteristics of deterministic calculation models

	taking into account the deterministic approach and using analytical dependencies	taking into account the influence of random factors on the course of processes by applying a probabilistic-statistical approach
definition	the largest number of applications that can be served by the system at a given time with a certain technical equipment and advanced work technology	the largest number of applications that can be missed by the system at a given time. At the same time, the probability of service in the calculation period of applications will be equal to or greater than the given probability value P
Formulas for calculation	$N_C = T_P / \bar{t}$, where: TR – estimated time period used for service of applications; $\bar{t}$ - duration of service with uniform and continuous use of the system during the calculation period.	$P(n \geq n_P) = \int_{n_P}^{\infty} W(n)dn$, where: W(n) is the probability density; n is a random variable
Advantages	unambiguity of the initial data, which includes external conditions, controllable and uncontrollable factors, which significantly simplifies the task	factors of a probabilistic nature are given by the average value of a random variable, as well as coefficients that take into

		account possible adverse deviations
Disadvantages	there is a probability of making an irrational decision, which is associated with the influence of random factors on the course of processes	only part of the initial information is deterministic, and the rest is replaced by statistical characteristics of random variables or functions
Application	used only for systems that operate without interruption and serve each unit during the time interval .	is used to assess the reliability of quantitative indicators, the values of which can take a continuous series of values, and most often consists in the calculation of a confidence interval (error) for a given probability of reliability

Source: compiled by the authors based on literary sources

A model with a given reliability requirement

The model is built on the basis of a classical process model, but taking into account the specified requirements for the reliability of the supply chain. Its essence isfinding the minimum total costs for the given requirement for the reliability (non-failure) of the supply chain and is expressed by the formula:

$$S_{\Sigma} = \sum_{i=1}^{n\Sigma} \sum_{j=1}^{m} S_{ij} \times X_{ij} \rightarrow min, \qquad (2.27)$$

for restrictions

$$\begin{cases} \sum_{j=1}^{m} X_{ij} = 1, \;\; \forall_i = \overline{1,n}; \\ \prod_{i=1}^{n} \sum_{j=1}^{m} P_{ij} \times X_{ij} = \beta; \\ \sum_{j=1}^{m} P_{ij} \times X_{ij} \geq \alpha_i, \forall_i = \overline{1,n};. \end{cases} \qquad (2.28)$$

where: $\{\alpha_i\}$ is a vector of constraints on process reliability $(\forall_i = \overline{1,n})$;

P_{ij} is the probability of failure-free implementation of the jth strategy in the ith process;

X_{ij} is a binary variable (choice variable) that takes the value either 0 or 1.

In contrast to the limitations of the classical model, in the system of constraints (2.28), equality appears in the constraints of the second type (the second row in the system of constraints (3.28)) and an additional constraint on the reliability of individual processes in supply chains (the third row in the system of constraints (2.28)).

The solution of the problem is a nonzero vector from the matrix , for which the total costs SΣ will be minimal $\{X_{ij}\}_{n}^{m}$.

It should also not be forgotten that any system usually consists of a number of component elements or a number of smaller systems or subsystems. Their interaction, as well as their dependence on each other, will affect the reliability of the system as a whole.

Thus, H. Taghizadeh and E. Hafezi, from the point of view of reliability, suggest that all supply chains be considered as systems in which components are connected to each other in one of five positions:

– sequential;

– parallel;

– parallel-serial;

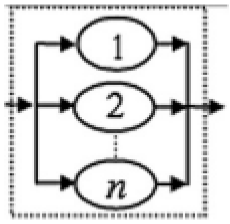
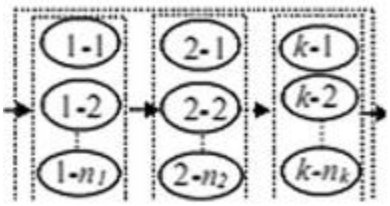
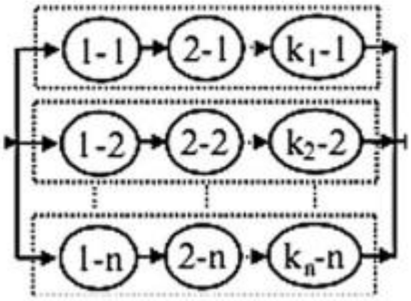
– series-parallel;

– composite[12].

---

[12]Taghizadeh H., Hafezi E. The investigation of supply chain's reliability measure: A case study, Journal of Industrial Engineering International, ISSN 2251-712X, Springer, Heidelberg, 2012, Vol. 8, 1-10, https://doi.org/10.1186/2251-712X-8-22

Table 2.8 – Structure and reliability calculation models depending on the position of supply chain components

Position	Figure	Mathematical model
Consistent		$C = P_1 \times P_2 \times \ldots \times P_n = \prod_{i=1}^{n} P_i$
parallel		$C = \prod_{i=1}^{n} \left[1 - \prod_{j=1}^{m} (1 - P_{ij}) \right]$
Series-parallel		$C_{ps} = \prod_{i=1}^{n} \left[1 - \prod_{j=1}^{m} \left(1 - C_{ps_{ij}}\right) \right]$
Parallel-serial		$C_{sp} = 1 - \prod_{j=1}^{n} (1 - C_{sp_j})$
Composite	Composite complex	To calculate the reliability in a composite complex, first the system must be divided into subsystemsb, and then by calculating the reliability of smaller subsystems, the reliability of the main systems can be calculated.

Source: compiled by the authors based on literary sources

And according to their structure (the positions of the components in relation to each other), form and apply the appropriate mathematical models in practical activities.

Table 2.8 presents various positions of the components of the supply chain and corresponding structures of its construction and mathematical models for calculating the reliability of each position.

Model of functional reliability.

Usually, outsourcing technologies in the process model of supply chain management are characterized by simple one-level functional schemes (see Fig. 2. 4):

1) with n channels of unlimited power;

2) with n channels of limited capacity exceeding demand;

3) with the availability of m channels of limited capacity, less than the demand[13].

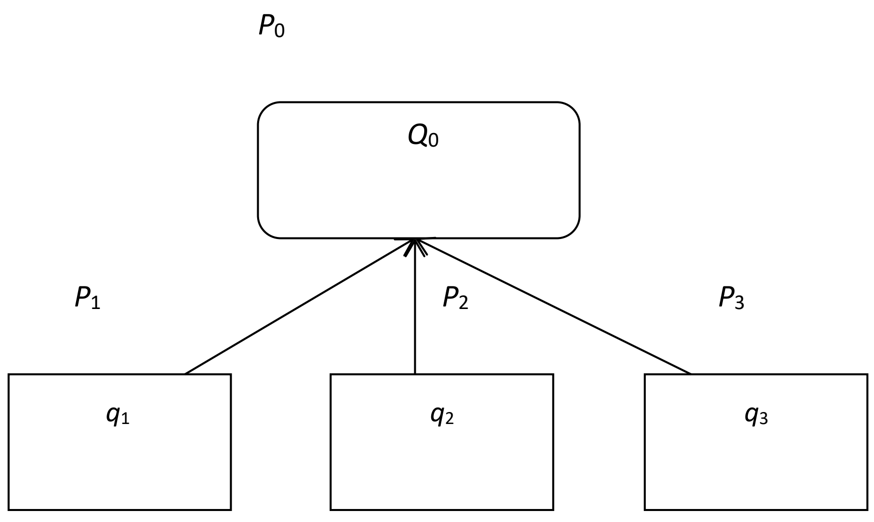
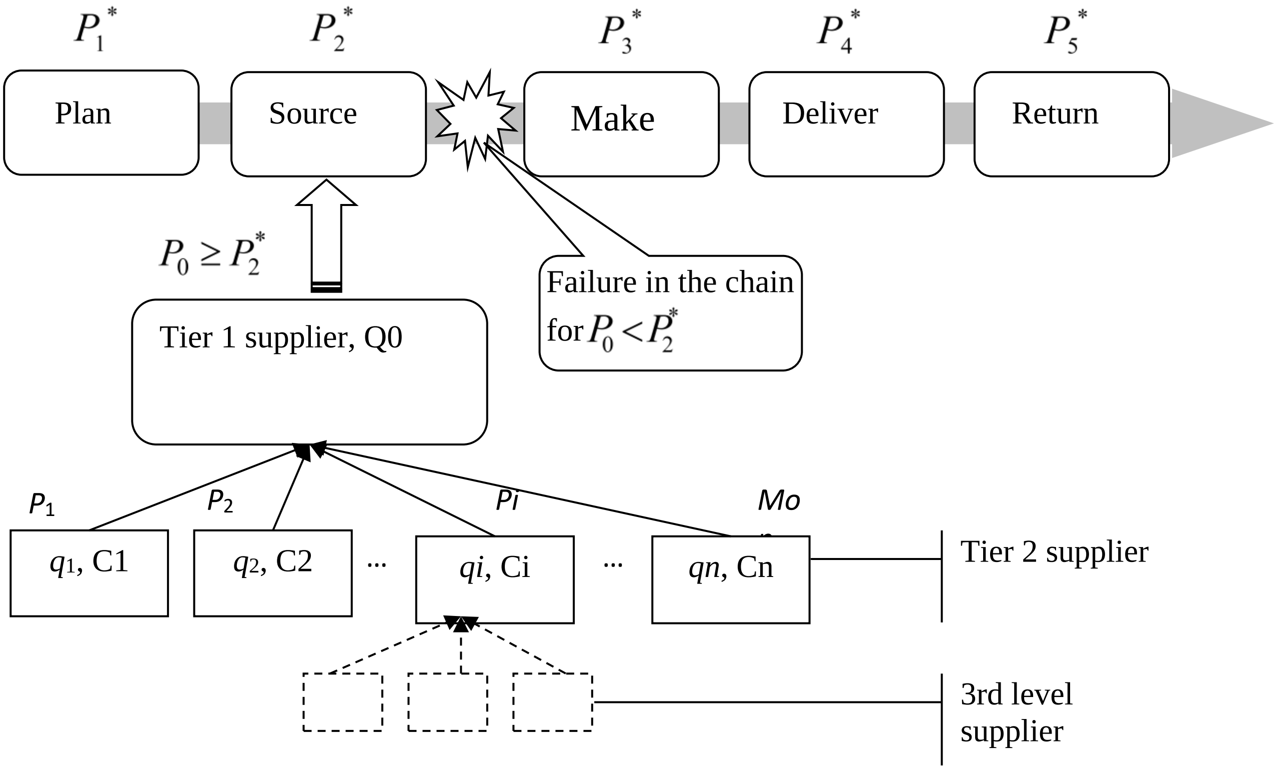


Fig. 2.4 Model of functional reliability

Source: compiled by the authors

[13] Abbasi M.,Varga, L. Steering supply chains from a complex systems perspective,European Journal of Management Studies, 2022, Vol. 27 No. 1, 5-38.https://doi.org/10.1108/EJMS-04-2021-0030

We will consider the supply organization scheme in this model using the example of the provision of the "Source" process in the classic SCOR model, which is graphically displayed in fig. 2.5.



Q0 is the required volume of supply for the planned time t0;

Pi, qi, Ci – probability of failure-free operation, power and cost of supplies on the i-th channel, respectively

Fig. 2.5 Functional scheme of the supply network

Source: compiled by the authors

Suppose that as a result of solving the normalization task, the requirement for non-failure is determined:

$$P_0(t_0) = \phi(P_1, P_2, \dots, P_n) \geq P_2^* \tag{2.29}$$

where: $\phi(P_1, P_2, \dots, P_n)$ – a function determined by the functional reliability scheme (redundancy scheme);

P_2^* – the end user's demand for reliability of supply, which is determined by the responsible supplier or supply operator (1st level supplier). P_2^*

If it is impossible to fulfill the contractual conditions on its own, the 1st-level supplier (see Fig. 2.5) forms a network of 2nd-level suppliers based on the principles of outsourcing, which, in turn, can form 3rd, 4th and further networks based on the same principleslevels Failures in the supply chain in this model are understood as independent events that consist in the violation of contractual conditions in one or more functional parameters. For example, such as time, sequence, completeness or scope of delivery.

Model of structural reliability.

In this model, to ensure the necessary reliability, the responsible supplier forms its own network of suppliers of the 2nd level with channels of different capacity, specific cost and reliability of supply. At the same time, the network must ensure uninterrupted supply with the volume of Q0 at the scheduled time t0 not lower than the reliability of P0 with minimal costs S0 (Fig. 2.6)$q_1, q_2, \ldots, q_n C_1, C_2, \ldots, C_n P_1^*, P_2^*, \ldots, P_n^*$.

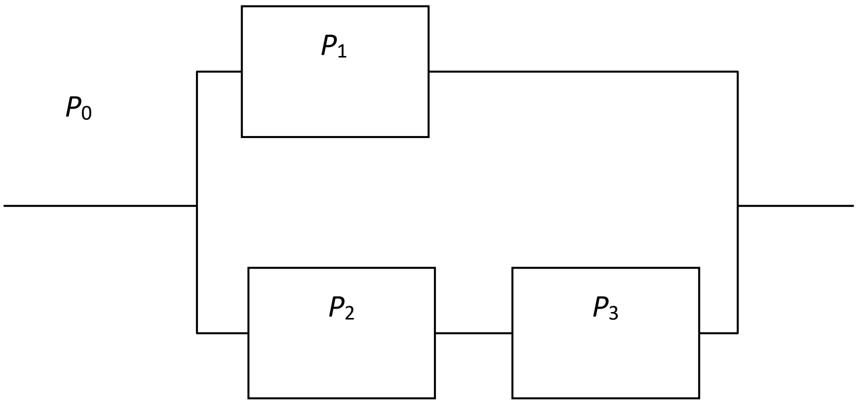


Fig. 2.6 Model of structural reliability

Source: compiled by the authors

The optimal supply plan in this case is found when solving the mathematical programming problem:

$$S_0 = \sum_{j=1}^{n}(C_j Z_j + R_j) \rightarrow min, \qquad (2.30)$$

for restrictions

$$\sum_{j=1}^{n} Z_j = Q_0, j = 1, \ldots, \rightleftarrows n;$$

$$0 \leq Z_j \leq q_j, j = 1, \ldots, n;$$

$$P_0(t) = \phi(P_1, P_2, \ldots, P_n) \geq P_2^*, \quad (2.31)$$

where: R_j – fixed costs for servicing the jth supply channel;

$\phi(P_1, P_2, \ldots, P_n)$ is a function determined by the scheme of structural reliability.

This model ensures the flexibility of deliveries with a specified fail-safe due to the possibility of regulating the volume of deliveries by channels. Disadvantages of regulation are determined by the constant maintenance costs of the involved channels. The problem is the calculation of failure, which requires the drawing up of structural reliability schemes equivalent to the functional supply model. The complexity lies in the large number of possible functional states of the system, especially in multi-level supply networks. Therefore, it is necessary to combine suppliers into chains, provided that it is possible to jointly ensure the requirements for the established criteria of functionality.

Just-in-time model (Just in Time– JIT).

Considering that transportation is a key logistics operation, the description of which is characterized by a large number of indicators and factors that significantly affect the timeliness and accuracy of deliveries, the logistics modelsupply of material resources"just in time" (JIT) can also be attributed to a variety of supply chain reliability models. After alltransport and logistics processes due to their uncertainty and the presence of risks thatdiffer in frequency and nature of occurrence of adverse eventsthere arethe most difficultwhen making decisions in supply chain management.

The main idea of the JIT system is manifested in the use of logistics tools as a method of managing material flows, when the components of these flows in the form of raw materials or materials, individual nodes and links of manufactured products will be delivered to the production process in accordance with production planning technologies, strictly observing quantitative, qualitative and time parameters. And if we consider the main conditions for implementing the JIT model, they fully meet the reliability criteria:

1. Placing an order for products must be regulated by the parameters of production capabilities.

2. Stocks of material resources should be optimal in accordance with the course of the production process.

3. Compliance with the production cycle should characterize the organization of production.

So, let's consider the situation that arises during the implementation of JIT technology in the supply chain from the point of view of its reliability. Thus, in the JIT model, a functional failure is defined as an event that exceeds the planned delivery time t0 of an order with a volume of Q0. At the same time$F(t > t_0)$ - the possibility of exceeding the planned order execution time in full. Suppose that $P_0(t_0)$ – the possibility of fail-safe operation is given. To ensure this level of reliability, it is necessary to form a network of n channels by analyzing the market of suppliers and evaluating their potential functionality. Then the functional condition of failure of the i-th supply channel will be determined by the expression:

$$t_i = \frac{Q_0}{\lambda_i} \leq t_0, \tag{2.32}$$

where: λ_i – potential intensity of supplies through the i-th channel.

It follows from (2.32) that two types of channels are possible in the network:

- basic – with the possible volume of supplies $q_i = \lambda_i t_0 \geq Q_0$;

- auxiliary - which do not independently provide the necessary volume of supplies for the planned period.

Auxiliary channels can be combined into supply chains under the following conditions:

$$t_j = \frac{Q_0}{\sum_{j=1}^{k} \lambda_j} \leq t_0, k < n. \quad (2.33)$$

A supply network with a series-parallel scheme of structural reliability is formed from the main channels and chains of auxiliary channels. Optimal supply plan $Z_i, i = 1,2,\ldots,n$ is a consequence of solving the problem of mathematical programming:

$$S = \sum_{i=1}^{n} C_i Z_i \rightarrow min, \quad (2.34)$$

for restrictions

$$\sum_{i=1}^{n} Z_i = Q_0, i = 1,\ldots,n;$$

$$0 \leq Z_i \leq q_i, i = 1,\ldots,n;$$

$$P(t \leq t_0) \geq P_0(t_0). \quad (2.35)$$

where: C_i,q_i – cost price and possible volume (capacity) of supplies for the i-th chain, respectively;

$q_i = \lambda_i t_0 P(t \leq t_0)$ is the reliability of supplies, determined by the model of structural reliability.

At the same time, it should be noted that, according to the SCOR concept, JIT is a model that is responsible for the "order cycle time" indicator. It is formed on the basis of the composition of the laws of distribution of stochastic variables Ti, which are the time of execution of logistics operations. The probability of timely execution of the logistics cycle can be:

$$P = \Phi(\frac{T_0 - T_c}{\sigma_T}), \quad (2.36)$$

where: T_0 is the delivery time according to the "just in time" model with probability P_0;

Ts – average delivery time;

σ_T is the root mean square deviation of the delivery time.

And given that the time characteristics of the transport process and the need to comply with the requirements for transportation, especially international transportation, are random characteristics, it is useful to take them into account when planning the reliability of global supply chains.

Yes, taking into account the above-mentioned features, the total time of transportation inJIT modelscan be determined by the formula:

$$T_0 = \sum_{i=1}^{A} t_i + \sum_{j=1}^{B} \tau_j + \sum_{k=1}^{C} \theta_k, \quad (2.37)$$

where; t_i – travel time;

τ_j – the time of processing customs documents at point j;

Θ_k – the time of loading, unloading and storage at the k-point;

A, B, C – the number of sections of the roads that the car travels on, customs and loading/unloading points.

Then, for international transportation, the formula for calculating the total time spent on the route must be adjusted and presented as follows:

$$T_0 = \sum_{i=1}^{A} t_i + \sum_{j=1}^{B} \tau_j + \sum_{k=1}^{C} \theta_k + \sum_{l}^{D} \varphi_l + \sum_{m=1}^{E} \psi_m + \sum_{n=1}^{F} \eta_n, \quad (2.\ 38)$$

where: ϕ_l is a random component showing an increase in driving time as a result of repairs and maintenance or other unforeseen reasons;

ψ_m is a random component reflecting restrictions related to the European Agreement on the work of crews of vehicles performing international road transport (ESTR);

η_n – a random component reflecting a ban on the use of heavy-duty vehicles;

D, E, F – the number of cases of downtime (taking into account the specified reasons).

However, in real systems, the limitations of the deterministic approach and using analytical dependencies are met extremely rarely, so it is advisable to use a probabilistic-statistical approach to determine the reliability of the supply chain.

2.2.3 Formation of stochastic models of supply chain reliability

Supply chain planning is a dynamic process, because decisions made in a given period rely on decisions that were implemented in previous periods and are related to decisions that will be made in later periods. Accordingly, resource allocation plans should explain the intertemporal nature of the decision-making process. Inventories of raw materials, work-in-progress, and finished goods play a central role in optimizing the impact of production and resource allocation decisions made on a period-by-period basis throughout the multi-period planning horizon.

Individual characteristics for the empirical distribution of supply chain reliability, as for most complex systems, are characterized by mean service time (mathematical expectation), variance, root mean square deviation, semivariance, standard deviation, and coefficient of variation.

The formulas for their calculations and the main characteristics of the indicators are given in Table 2.9.

Table 2.9 – System of indicators of absolute and relative measurement

Indicator	Calculation formula	Characteristic
Mathematic alhope	*For a discrete quantity* $$M(x) = \sum_{i=1}^{\infty} x_i \cdot p_i,$$ where chi is the value of a random variable, and = 1, 2,..., ri are the corresponding probabilities.	The mathematical expectation associated with an uncertain situation is a weighted averageof all possible outcomes, where the probability of each of them is used as the frequency or specific

		weight of the corresponding value.
	For a limited number (n) of possible values of a random variable $$M(x) = \sum_{i=1}^{n} x_i \cdot p_i.$$ *For a random continuous value x* $M(x) = \int_{-\infty}^{x} x \cdot f(x)\, dx$or $M(x) = \int_{a}^{b} x \cdot f(x)\, dx,$ if a continuous random variable is defined on the interval [a, b], where f(x) is the probability density	Expected value measures the result that is expected on average. The probabilistic meaning of the mathematical expectation of a specific parameter is that it is approximately equal to the arithmetic mean of its possible values
Dispersion	*For a random variable X* $$D(x) = M\{\left(x - M(x)\right)2\}.$$ *For a discrete random variable X* $$D(x) = \sum_{i=1}^{n} (x_i - M(x))^2 \cdot P_i$$ *For a continuous quantity X* $D(x) = \int_{-\infty}^{x} \left(x - M(x)\right)^2 \cdot p_i dx$or $$D(x) = \int_{a}^{b} \left(x - M(x)\right)^2 \cdot f(x) dx$$	Variance is the weighted average of the squared deviations of the actual results from the expected averages. It characterizes the dispersion of the value of a random parameter from its average predicted value

Mean-square deviation	$\delta(x) = \sqrt{D(x)}$	Shows the maximum possible fluctuation of a certain parameter from its average expected value and makes it possible to assess the degree of risk from the point of view of the probability of its realization
Semivariation $(S_{VAR}^{+}, S_{VAR}^{-})$	$S_{VAR}^{+} = {}^{1}/_{P=} \times \sum (a_{ij} - M_j)^2 \times$ $\times P_j \times \alpha_{ij}$, where P is the total probability of the occurrence of those external conditions that give a probability greater than the average value	Positive semivariation characterizes the dispersion of those values that are greater than the average. The greater its value, the greater is the solution expected from the option. Negative semivariance characterizes the dispersion of those values that are smaller than the average.
Semiquadratic deviation $(SS_{VAR}^{+}, SS_{VAR}^{-})$	$SS_{VAR}^{\pm} = \sqrt{S_{VAR}^{\pm}}$	Positive semiquadratic deviation of the absolute value of the

		indicator; shows the absolute distance at which the value of the indicator is greater than the average (mathematical expectation). The negative semiquadratic deviation characterizes the deviation of the absolute value of the expected indicator. The greater the value of the indicator, the lower the risk
Coefficient of variation K(x)VAR	$K(x)_{VAR} = \delta(x)/M(x)$, where δ(x) is the root mean square deviation, M(x) is the expected value	Compares the riskiness of areas of activity and specific situations according to features expressed in different units of measurement. The coefficient of variation can vary from 0 to 100%. The smaller the value, the

		more stable the forecasted situation is and, accordingly, the lower the degree of risk of carrying out a certain measure

Source: compiled by the authors based on literary sources

However, the most informative characteristic of a random variable is the law of distribution of the probability of its occurrence, which relates the specific value of the random variable (the processing of the supply order) with the probability of the occurrence of this event (that is, the occurrence of this value as a result of the experiment).

Mathematically, the law of probability distribution can be represented by the Gaussian equation and the RTi density

$$f(t) = P_{T_i} = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(\bar{t} - t_i)^2}{2\sigma^2}\right] = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\bar{t}-t_i)^2}{2\sigma^2}} \tag{2.38}$$

where: e=2.718 is a mathematical constant, the base of the natural logarithm.

Formula 2.38 is graphically displayed in Fig. 2.7. in the form of a sinusoid, symmetrical about the center of the distribution of the probability of reliable execution of the order (the maximum of the function).

Therefore, in order to maintain the reliability of objects that are prone to failures, reserve capacities should be created to meet the needs of consumers of products during failures.Dynamic and stochastic approaches are used to account for uncertainty in modeling such problems[14].

---

[14]Setak M., Feizizadeh F., Tikani H., Shaker Ardakani E. A bi-level stochastic optimization model for reliable supply chain in competitive environments: Hybridizing exact method and genetic algorithm, Applied Mathematical Modelling, Volume 75, 2019, 310-332.

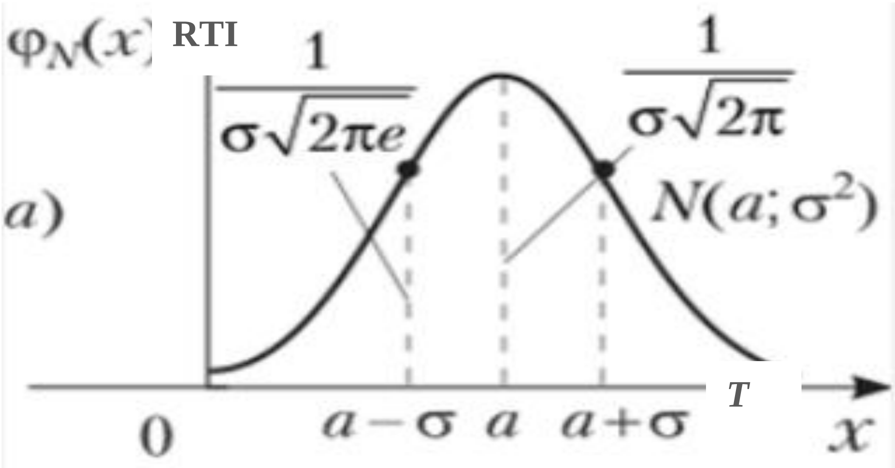


Fig. 2.7 The probability density distribution curve of reliable order fulfillment

Source: compiled by the authors

It should be noted that in recent years there have been many works devoted to the application of dynamic and stochastic programming methods for planning production and trade processes[15] as well as for other key business processes in the supply chain, including logistics: warehousing[16] transportation[17] etc.

In them, the main indicators of the supply chain, which determine its reliability, also include reliability, reproducibility, and costs for maintaining operational efficiency. Moreover, the first two can be characterized by probabilistic characteristics of supply chain operations, combining different

[15]Nezhad F, Mohammad S. A Stochastic Dynamic Programming for Production Planning of Process Industries. A Stochastic Dynamic Programming for Production Planning of Process Industries. 2016. 27. 547-562.; Li L., Liu M., Shen W., Cheng G. An improved stochastic programming model for supply chain planning of MRO spare parts, Applied Mathematical Modelling, Volume 47, 2017, 189-207.; Kungwalsong K. Cheng C.-Y., Yuangyai C., Janjarassuk U. Two-Stage Stochastic Program for Supply Chain Network Design under Facility Disruptions. Sustainability 2021, 13, 2596.https://doi.org/10.3390/su13052596.;Quezada F., Gicquel S, Kedad-Sidhoum S., Vu DQ A multi-stage stochastic integer programming approach for a multi-echelon lot-sizing problem with returns and lost sales, Computers & Operations Research, Volume 116, 2020, 104865.

[16]Coelho LC, Cordeau JF., Laporte G. Heuristics for dynamic and stochastic inventory-routing, Computers & Operations Research, Volume 52, Part A, 2014, 55-67. ;Han C., Jeon H., Oh J., Lee H. Dynamic Order Picking Method for Multi-UAV System in Intelligent Warehouse. Remote Sens. 2022, 14, 6106. https://doi.org/10.3390/rs14236106

[17]Powell WB, Simao HP, -Ayari VV. Approximate dynamic programming in transportation and logistics: a unified framework, EURO Journal on Transportation and Logistics, Volume 1, Issue 3, 2012, 237-284. Carkovs J., Matvejevs A., Matvejevs A., Kubzdela A. Stochastic modeling for transport logistics, Procedia Computer Science, Volume 149, 2019, 457-462.

methods of their calculation in relation to various types of failures. Regarding the third, it is recommended to take it into account depending on the probability (frequency) of failures in combination with the other two indicators (Fig. 2.8 - 2.10).

Indicator	Calculation formula	Clarification
reliability	$P = 1 - \frac{N}{n}$	N – the number of k failures in the jth operation for n implementations.
renewability		N – number of eliminated k-th failures in j-th operation for n implementations.
costs of maintaining working capacity		N – the number of cases of failure elimination costs in the jth operation for n implementations.

Fig. 2.8 Ways of calculating probabilistic characteristics of operations based on accounting for emerging events

Source: compiled by the authors based on literary sources

Indicator	Calculation formula	Clarification
reliability	$P = \frac{\Pi - \delta}{\Pi}$	П – planned supply value of the jth operation; δ – average deviation from the plan in the jth operation for n realizations
renewability	$P = \frac{\delta}{\delta^{*}}$	δ – average deviation from the plan in the jth operation for n implementations; δв - average value of the planned indicator recovery in the jth operation for n implementations.
costs of maintaining working capacity	$C = \frac{\sum_{i=1.k=1}^{n.z} \times C_{ik}}{n}$	Ci,k - costs for eliminating the k-th failure in the i-th operation.

Fig. 2.9 Ways of calculating probabilistic characteristics of operations based on quantitative characteristics

Source: compiled by the authors based on literary sources

Indicator	Calculation formula	Clarification
reliability renewability costs of maintaining working capacity	$K_r = \frac{\Pi}{\Pi + \Pi_r}$	П – the average size of the supply indicator in the jth operation; Пr – average value of the recovery of the supply characteristic of the jth operation.

Fig. 2.10 Methods of calculating the probability characteristics of operations based on the availability ratio

Source: compiled by the authors based on literary sources

For this reason, dynamic models spanning multiple time periods have become widespread in supply chain reliability management, as opposed to static models that are developed for a single time period. Dynamic linear programming models, like static models, are deterministic, meaning that parameters such as demand and resource prices are constant. If these conditions are not met, stochastic linear programming models are used.

Stochastic linear programming models are an attractive choice for any type of planning (operational, tactical or strategic)[18], because their application allows the manager to analyze inaccuracies in detail and manage risks. Their application makes it possible to simultaneously consider many scenarios of the unknown future, and each with its own probability of occurrence.

Such a model simultaneously determines the optimal random plan for each scenario and the optimal warning plan that differs from all random plans. Optimization includes the maximization (or minimization) of expected revenues (costs), where the term "expected" means the product of the revenues (incomes) of each scenario and their probabilities.

This type of model is widely used in cases where certain factors are uncertain. In them, the presence of unsatisfied demand is allowed, accordingly, the order is placed only when the amount of stock reaches the level R, which is a function of the time period between the placement of the order and its execution (Fig. 2.11).

In this model, the optimal values of "y" and "R" are determined by minimizing the ratio of expected costs of the inventory management system per unit of time. When building the model, assumptions are made that unsatisfied demand during the order execution time accumulates, only one unfulfilled order is allowed, and the distribution of demand during the order execution time is stationary (constant) in time.

---

[18] van Delft Ch., Vial J.-Ph. A practical implementation of stochastic programming: an application to the evaluation of option contracts in supply chains, Automatica, Volume 40, Issue 5, 2004, 743-756.

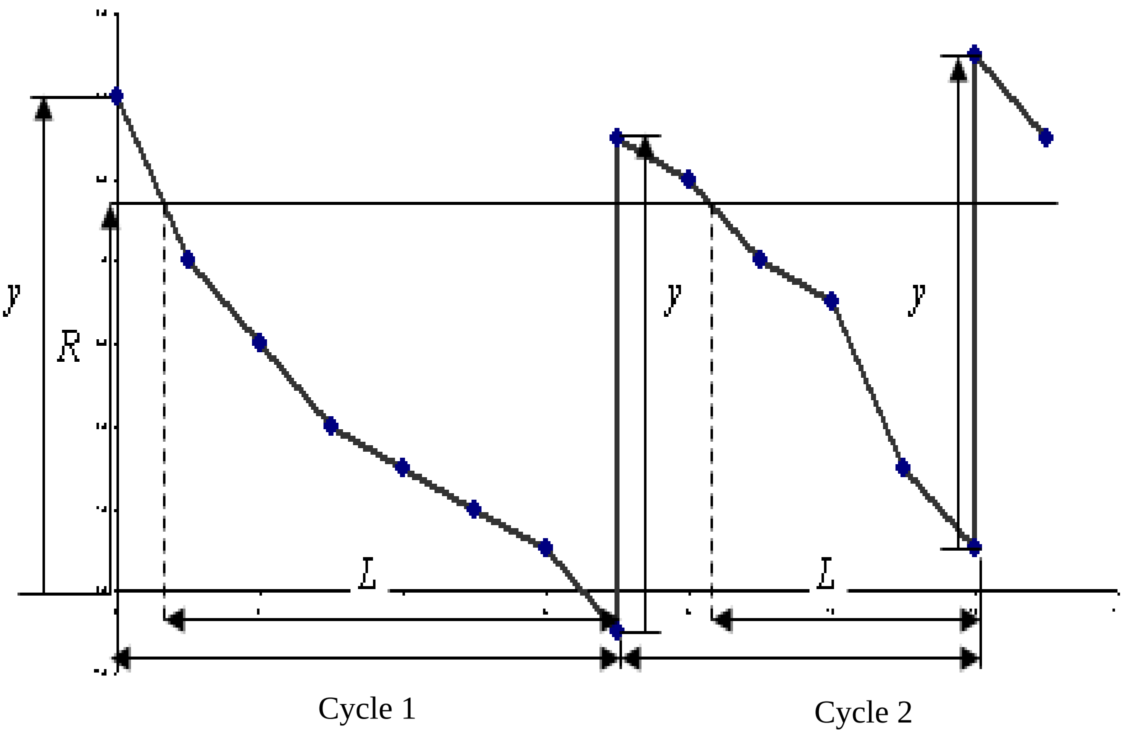


Fig. 2.11 Scheme work models ofstochastic (andprobability) system of optimal order size.

Source: compiled by the authors

Thus, the total cost function per unit time consists of three components: the cost of placing an order, expected storage costs, and losses expected from unsatisfied demand (the case when R–M{x}<0 is ignored) has the following form:

$$TC(y,R) = D \cdot K/y + h \cdot (y/2 + R - M\{x\}) + p \cdot D/y \int_R^{\infty} (x-R) \cdot f(x)dx, \quad (2.39)$$

where: D – the expected value of demand per unit of time;

p – specific losses from unsatisfied demand;

f(x) – the density of the distribution of demand x for the time of order fulfillment.

The values of y* and R* are determined by a numerical method[19] provided that an admissible solution exists. When R=0:

$$\bar{y} = \sqrt{\frac{2D\cdot(K+pM\{x\})}{h}} \text{and} \tilde{y} = \frac{p\cdot D}{h} \quad (2.40)$$

If $\tilde{y} \geq \bar{y}$, then there is a single optimal value for y and R.

The minimum value is calculated according to Wilson's formula[20]

$$\text{for S=0.} y^* = \sqrt{2D\cdot K/h} \quad (2.41)$$

The optimal values of y* and R* are found by the methods of differential calculations according to the formulas:

$$y^* = \sqrt{\frac{2D\cdot(K+pS)}{h}} \quad (2.42)$$

$$\text{and} \int_{R^*}^{\infty} f(x)dx = \frac{h\cdot y^*}{p\cdot D} \quad (2.43)$$

where: S is the expected shortage of a material resource per unit of time.

The advantage ofstochastic (probability) modelsthere is their flexibility, which allows you to more accurately take into account the real features of the production consumption of material resources.

The disadvantages include the use of a complex mathematical apparatus based on the theory of probabilities and mathematical statistics and the difficulty in determining the probability of non-deficit work due to the fact that it is not possible to accurately predict force majeure circumstances that may arise during supplyof a wholesale batch of goods or in the work of the enterprise.

The number of models of dynamic and stochastic programming is huge, and the scope of their application goes far beyond the limits of a separate study. The most popular among them are: a dynamic model of the task of optimizing the lot size and choosing suppliers, taking into account the area of warehouse

[19]Brown BM, Kirby VG, Pryce JD A Numerical Method for the Determination of the Titchmarsh-Weyl m-Coefficient Proceedings: Mathematical and Physical SciencesVol. 435, No. 1895 (Dec. 9, 1991), 535-549.; Butcher JC Numerical methods for ordinary differential equations in the 20th century, Journal of Computational and Applied Mathematics, Volume 125, Issues 1–2, 2000, 1-29.

[20] Wilson RH A scientific routine for stock control. Harv. Bus. Rev. 1934, 13, 116-129.

premises[21] and budget constraints and a stochastic model of the same task under conditions of changing demand[22].

Consider the first model. So in the work of C. Woarawichai, T. Kullpattaranirun and V. Rungreunganun[23] a mathematical statement of the task of calculating the size of the batch and selecting suppliers, taking into account the area of warehouses and budget constraints, is proposed.

Solving this problem allows you to determine the optimal lot size for each supplier and minimize total procurement costs, which include product acquisition costs, transaction costs for suppliers, and storage costs for remaining inventory. It is assumed that the demand for goods is known throughout the planning period. The task is formalized as a linear programming problem, let's consider its mathematical formulation. For this, we introduce the following notation.

Indexes:

$i \in \{1, \dots, I\}$– many product indexes;

$i \in \{1, \dots, J\}$– many supplier indexes;

$i \in \{1, \dots, T\}$ –many time period indexes.

Parameters:

Dit – demand for the product and in the time period t;

Pij – the price of product i at supplier j;

Hi – storage costs for product i for the period;

[21]Chirawat W., Tarathorn K, Vichai R. Inventory Lot-Sizing Problem with Supplier Selection under Storage Space and Budget Constraints // IJCSI International Journal of Computer Science Issues, Vol. 8, Issue 2, March 2011. 250-255.; Sadjadi SJ, Makui A., Dehghani E., Pourmohammad, M. Applying queuing approach for a stochastic location-inventory problem with two different mean inventory considerations, Applied Mathematical Modelling, Volume 40, Issue 1, 2016, 578-596.; Castaneda J., Ghorbani E., Ammouriova M., Panadero J., Juan AA Optimizing Transport Logistics under Uncertainty with Simheuristics: Concepts, Review and Trends. Logistics 2022, 6, 42. https:// doi.org/10.3390/logistics6030042.

[22]Mohammadi M. Designing an integrated reliable model for stochastic lot-sizing and scheduling problem in hazardous materials supply chain under disruption and demand uncertainty, Journal of Cleaner Production, Volume 274, 2020, 122621.;Kungwalsong K., Cheng C.-Y., Yuangyai C., Janjarassuk U. Two-Stage Stochastic Program for Supply Chain Network Design under Facility Disruptions. Sustainability 2021, 13, 2596.https://doi.org/10.3390/su13052596.;Vaez R., Sabouhi F., Saeed Jabalameli M. Sustainability in a lot-sizing and scheduling problem with delivery time window and sequence-dependent setup cost consideration, Sustainable Cities and Society, Volume 51, 2019, 101718.

[23]Chirawat W., Tarathorn K, Vichai R. Inventory Lot-Sizing Problem with Supplier Selection under Storage Space and Budget Constraints // IJCSI International Journal of Computer Science Issues, Vol. 8, Issue 2, March 2011. 250-255.

Oh – transaction costs for supplier j;

wi – area allocated for storage of product i;

S – total storage area;

Bt – the purchasing budget for the time period t.

Decision variables:

Xijt – number of products i ordered from supplier j in time period t;

Yjt – a variable that takes the value 1 if an order is made from supplier j in period t, otherwise 0.

Auxiliary variables:

Rit is the number of products i transferred from period t to period t +1.

It is necessary to calculate the variables Xijt, and Yjt, whichtransform to a minimum linear form

$$TC = \sum_i \sum_j \sum_t P_{ij} X_{ijt} + \sum_j \sum_t O_j Y_{jt} + \sum_i \sum_t H_t \left(\sum_{k=1}^{t} \sum_j X_{ijk} - \sum_{k=1}^{t} D_{ik}\right) \rightarrow min \quad (2.44)$$

subject to:

$$\begin{cases} R_{ij} = \sum_{k=1}^{t} \sum_j X_{ijk} - \sum_{k=1}^{t} D_{ik} \geq 0, \forall i, t; \\ (\sum_{k=1}^{T} D_{ik}) Y_{jt} - X_{ijt} \geq 0, \forall i, j, t; \\ \sum_i w_i \left(\sum_{k=1}^{t} \sum_j X_{ijk} - \sum_{k=1}^{t} D_{ik}\right) \leq S, \forall t; \\ \sum_i \sum_j P_{ij} X_{ijt} \leq B_t, \forall t; \\ Y_{jt} \in \{0,1\}, \forall j, t; \\ X_{ijt} \geq 0, \forall i, j, t; \end{cases} \quad (2.45)$$

The objective function shown in expression (2.44) consists of three parts:

1) price of goods;

2) transaction costs of suppliers;

3) cost of storage for products remaining for t+1 period.

The first constraint indicates that demand constraints must be met in the period in which they occur: shortages or backorders are not allowed.

The second constraint indicates that the execution of all orders incurs corresponding transaction costs, i.e. if the variable Yjt takes the value 0 in the time period k = t, then Xijt is also equal to 0.

The third limitation is imposed on the useful storage area of goods in the warehouse.

The fourth constraint indicates that the total cost of purchases for each product should not exceed the budget for the period.

The fifth constraint indicates that Yjt is a Boolean variable that takes the value 0 or 1;

The sixth constraint indicates that the decision variables Xijt, must be non-negative.

In general, finding a solution for such models is a rather difficult task in which the interaction between many variables must be taken into account. Therefore, it is better to use simpler models for real calculations. For example, researchers can break a complex stochastic problem into several simpler problems. As a result, they replace their variables with average values or solve a transformed certain problem under different scenarios and combine them using heuristic methods.

2.2.4 Formation of supply chain reliability simulation models

Forecasting the reliability of supply chains can also be done with the help of heuristic methods, which are practically indispensable in strategic planning (forecasting for a distant perspective of 3-5 years).

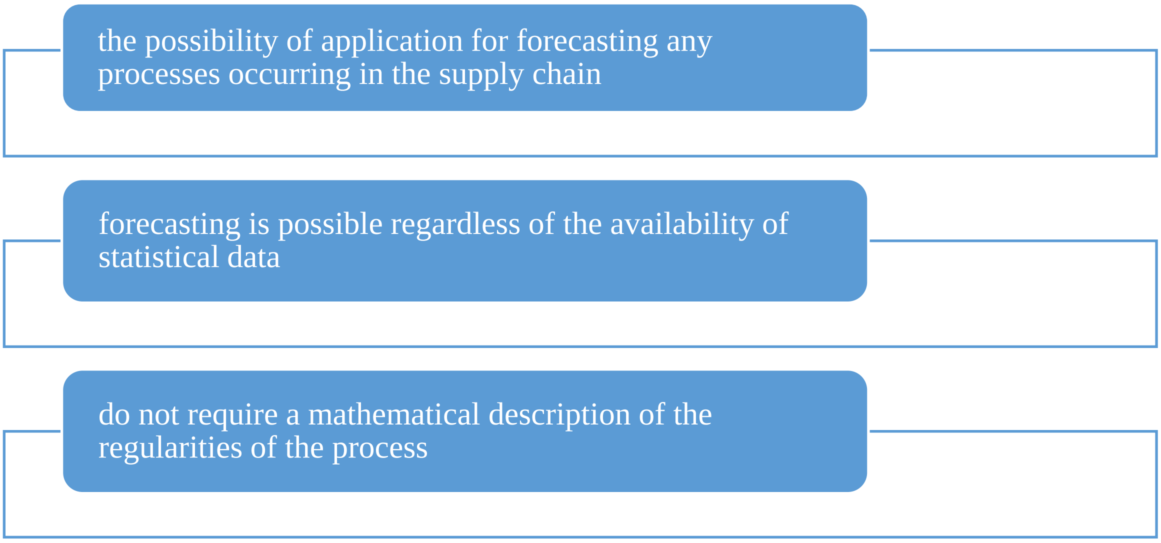


Fig. 2.12 Advantages of heuristic research methods

Source: compiled by the authors

However, these methods have two drawbacks.

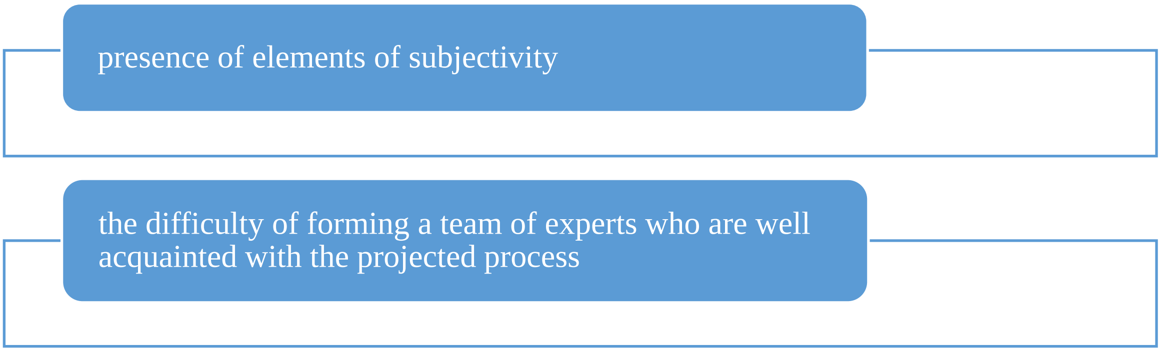


Fig. 2.13 Disadvantages of heuristic research methods

Source: compiled by the authors

Toheuristic methods, which are widely used in the assessment of the reliability of the supply chain, include simulation or simulation models that make it possible to simulate some individual processes of the system or company with the help of a computer.

The essence of this method lies in the development of such software algorithms that will be able to reflect the behavior of the system and its activity indicators within the scope of the study of virtual changes in the existing structure of the company's system.

The initial stage of the modeling process is the determination of the purpose of model development and its purpose. As for the goal, it can be designing, controlling or evaluating (including from the point of view of reliability) existing strategies in business and making informed management decisions on its basis.

Fig. 2. 14 General principle of building simulation models

Source: Chilmon B., Tipi N. Modeling an End to End Supply Chain System Using Simulation'. In: UK Operational Research Society - Simulation Workshop 2016 (SW16), 11-13 April 2016, Stratford, Worcestershire, United Kingdom

In simulation modeling, a method is understood as a certain basis, which is used to "translate" the system from the real world to the world of models. The method provides a certain language, "terms and conditions" for the development of the model. AND. Lowe and D. Kelton[24] other authors distinguish 3 main types of simulation models[25] generally support this classification and add modifications to these models.

Table 2.10 – Types of simulation modeling and their characteristics

Method name	The essence of the method	Advantages of the method	Disadvantages of the method
Event-based modeling	It is a set of events that occur in the system and rules that determine how the system should respond to these events. It is used for modeling discrete systems.	More efficient use. suitable for modeling discrete systems with a large number of events and variables.	Not suitable for modeling continuous systems, may lead to errors related to the order of processing events
Process-based modeling	It is a set of processes occurring in the system and rules that determine how the system should	Suitable for modeling continuous systems, more	More complex programming can lead to errors associated with changing the

[24]Law A., Kelton D. Simulation Modeling and Analysis. 2nd ed. New York; Madrid etc: McGraw-Hill 1991 759

[25]O. Ozkan, S. Kilic, A Monte Carlo Simulation for Reliability Estimation of Logistics and Supply Chain Networks, IFAC-PapersOnLine, Volume 52, Issue 13, 2019, 2080-2085.;Kumar D.,Sony G.,Kazancoglu Y.,Rathore APSOn the nature of supply chain reliability: models, solution approaches and agenda for future research",International Journal of Quality & Reliability Management, 2023. Vol. ahead-of-print No. ahead-of-print.https://doi.org/10.1108/IJQRM-08-2022-0256

	respond to these processes. It is used for modeling continuous systems. It has a model	efficient use of data	system state during the simulation process
Agent-based modeling	Each agent is a separate element of the system that can interact with other agents and change its behavior depending on conditions. It is used to model complex systems in which many agents interact	Suitable for modeling complex systems with many interacting elements, more flexible software	More complex software, higher performance requirements can lead to errors related to the interaction of agents

Source: compiled by the authors based on Law A., Kelton D. Simulation Modeling and Analysis. 2nd ed. New York; Madrid etc: McGraw-Hill 1991 759.

Each method is applied in a certain range of abstraction levels. Process-based system dynamics involves a very high level of abstraction and is typically used for strategic modeling. Discrete modelingevent-based supports medium and low levels of abstraction. Between them are agent models, which can be both very detailed, when agents represent physical objects, and extremely abstract, when competing companies or state governments are modeled with the help of agents.

Simulation models can be built on various mathematical algorithms, but they all require software. There are several types of simulation software. Table 2.11 presents a comparative analysis of several of them.

Table 2.11 – Comparison of simulation modeling tools

	anyLogistix	Anylogic	FlexSim	ARGoS	Repast
Creating a model with different types of components	+	+	+	+	+
Imitation of physical properties	+	-	-	+	-
Availability of support for communication between agents	-	+	-	+	-
Support for computing on clusters	+	-	+	-	+

Source: compiled by the authors based onFeliciani T., Luo J., Ma L, Lucas P., Squazzoni F., Marušić A., Shankar K. A scoping review of simulation models of peer review. Scientometrics. 2019; 121(1): 555-594. doi: 10.1007/s11192-019-03205-w. Epub 2019 Aug 19. PMID: 31564758; PMCID: PMC6744516.; Grznár P., Gregor M., Krajčovič M., Mozol Š., Schickerle M., Vavrík V., Ďurica L., Marschall M., Bielik T. Modeling and Simulation of Processes in a Factory of the Future. Appl. Sci. 2020, 10, 4503.https://doi.org/10.3390/app10134503.; Margariti SV, Dimakopoulos VV, Tsoumanis, G. Modeling and Simulation Tools for Fog Computing–A Comprehensive Survey from a Cost Perspective. Future Internet, 2020, 12, 89.https://doi.org/10.3390/fi12050089; Hoffa-Dabrowska, P.; Grzybowska K. Simulation Modeling of the Sustainable Supply Chain. Sustainability 2020, 12, 6007. https://doi.org/10.3390/su12156007

Let's focus on the most popular of them.

One of the management information systems that is widely used in the world to analyze the reliability of supply chains is anyLogistix (Fig. 2.15). She:

– combines analytical optimization (the classic anyLogistix chain design method) and dynamic modeling in one platform;

– using anyLogistix and operational data, you can design, analyze and modernize all elements of the supply chain.

– gravity analysis (Greenfield analysis or GFA) in anyLogistix can be very useful in the early stages of supply chain design. Using a minimum amount of raw data, it will help determine the optimal number of warehouses or production sites, as well as suggest where they are best located. In contrast to chain optimization, gravity analysis does not require inventing possible options for the location of objects.

– anyLogistix provides a set of tools to make informed decisions about supply chain optimization, including a demographic database. This helps to locate new facilities taking into account population and customer demand.

An experiment on network optimization will help to find the optimal location of objects, the value of transport and production flows, the levelstocksat the end of each period and related expenses. Moreover, you will have data on all possible network configuration options, including those with the lowest costs.

Also, the AnyLogic modeling system (Fig. 2.16) has become widely used as a tool for simulation modeling of discrete processes in modern practice. It is developed on the basis of modern concepts in the field of information technologies and research results in the theory of hybrid systems and object-oriented modeling. This is a comprehensive tool that covers the main areas of modeling in one model.

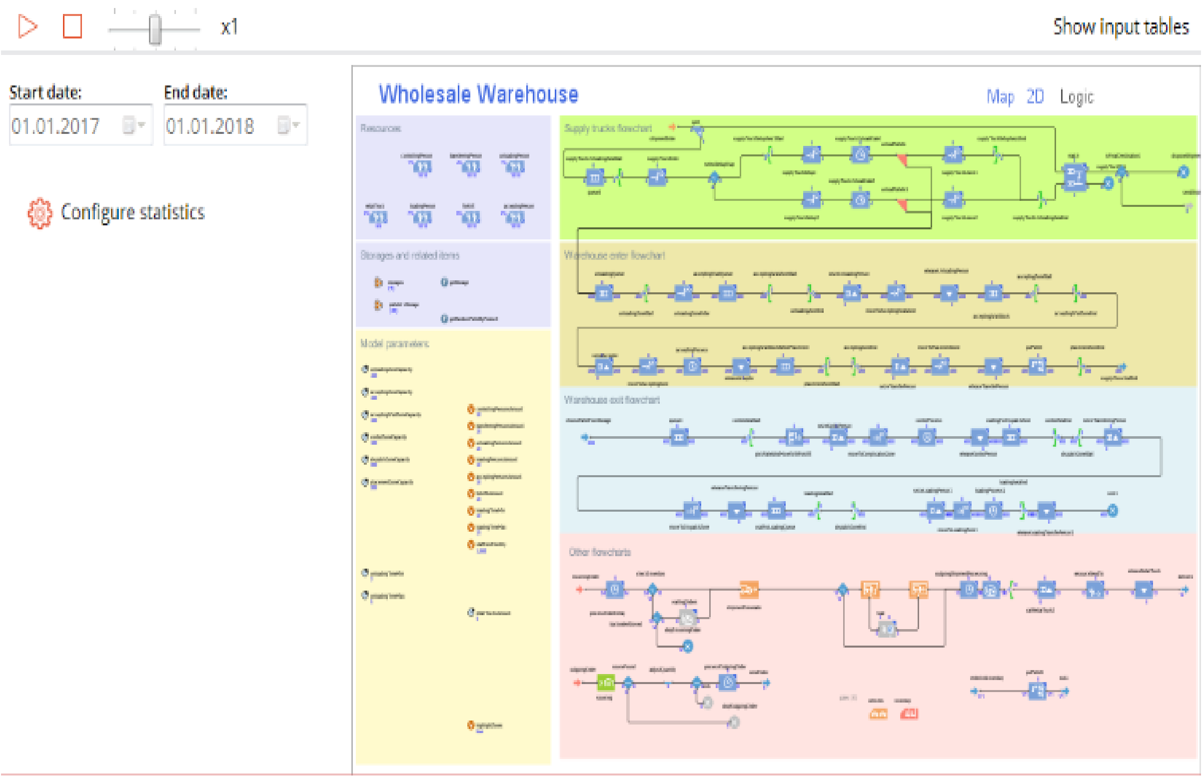


Fig. 2.15 Built-in modelanyLogistix in the supply process logic.

Source: Supply Chain Simulation and Optimization with anyLogistix

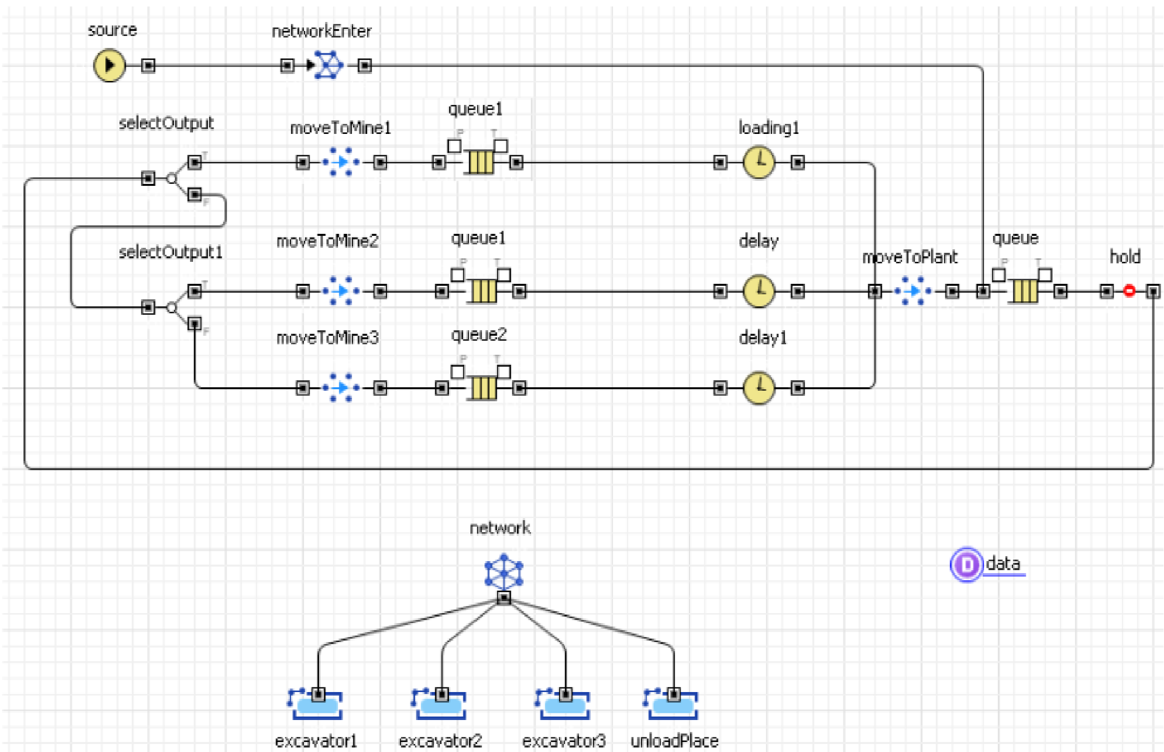


Fig. 2.16 Supply process model in AnyLogic

Source: AnyLogic 8.

FlexSim –is a state-of-the-art 3D modeling software. The logical supply process is built using the process flow module built into the FlexSim software (Fig. 2.17).

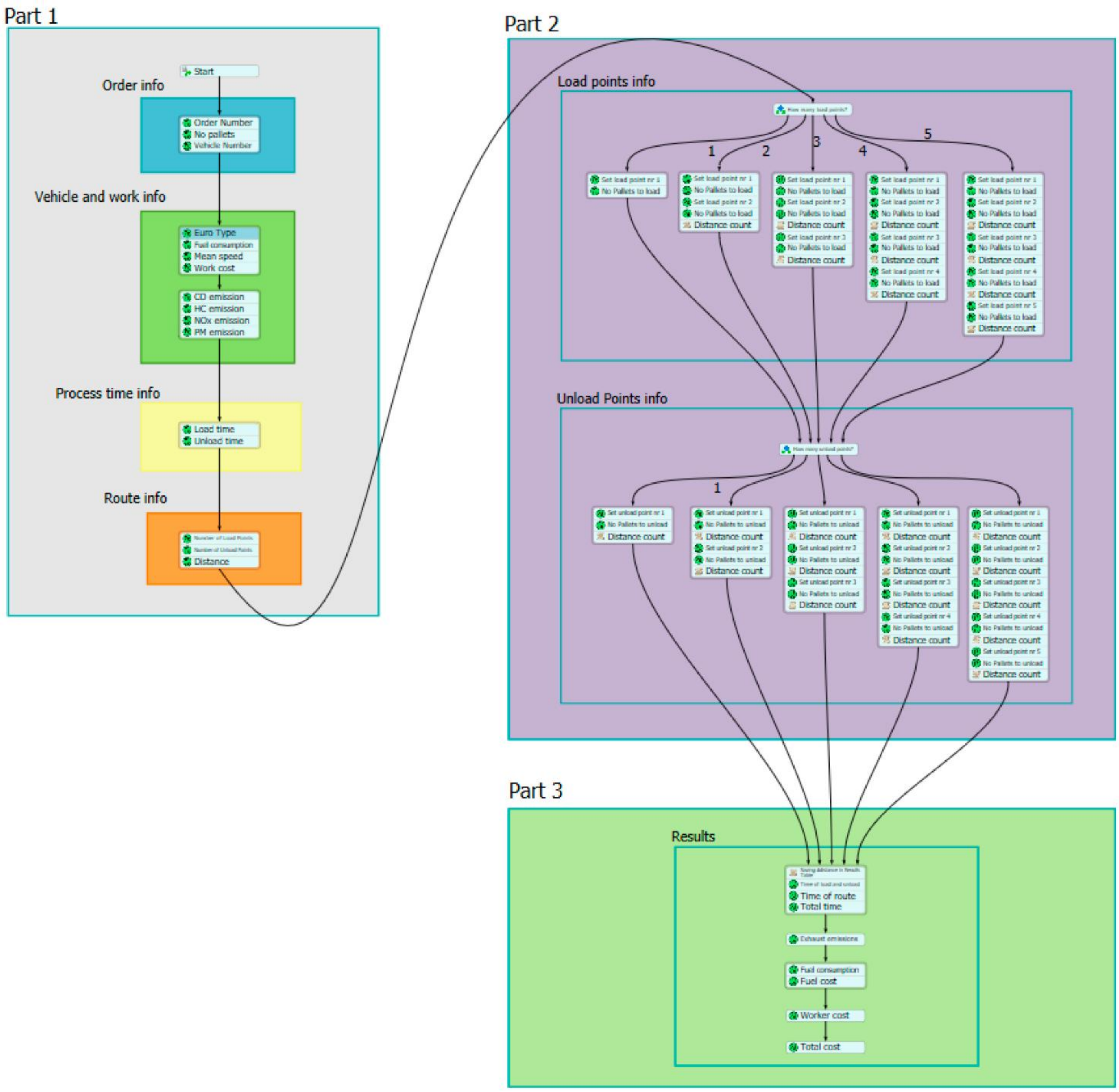


Fig. 2.17 Logistic process model in FlexSim

Source: FlexSim Home Page. Available online:https://www.flexsim.com/

In the FlexSim model, the logical process can be divided into three parts:

The first part – in which the basic information from the global tables is loaded, namely:

– order information;

– information about the vehicle and the employee, the order processing time;

– route information.

The second part includes information on the loading and unloading points for each order.

Part three is where the results are calculated and stored in the Results table for later presentation.

The logical process looks simple. However, some program code is added to each point, which takes into account the cooperation and connection of transport orders.

The advantage of using simulation (simulation) models is the possibility of conducting tests in various conditions and scenarios that can affect the operation of the supply chain. For example, it is possible to test the operation of the supply chain in the conditions of changing climatic conditions, changing consumer preferences, etc. The disadvantage of these models is the need to have accurate data and parameters to build the models. In addition, simulation models can be complex and time-consuming to implement.

2.3 Blevel models of supply chain reliability

The latest stage of economic development, which experts call the "economy of interactions" or the "economy of competences", is directly associated with the spread of network structures and organizations, the effective operation of which requires a new quality of interactions and management, which is connected with the integration of processes and organizations into a single whole . And since the supply chain is defined by many interconnected (interdependent) elements, it can be considered as a network logistics system, which, in turn, consists of lower-level systems (micro-logistics systems) and at the same time is a component of meso-, macro and mega level.

The formation of a multi-channel sales model forms a fundamentally new role of logistics, which in the current phase of online retail development not only provides the opportunity to differentiate the product and service offer, but also creates an additional barrier to entering the market, increasing the monetization of retail in digital sales channels. And it is the combination of logistics and service in online retail that becomes the main catalyst for the development of the modern commodity market. That is, there is not only a change in supply chains, but also a change in the entire transport, logistics and warehouse infrastructure, which must now be structurally restructured and serve the multi-channel logistics of market supply. The institutional transformation of supply chains, in turn, is accompanied by profound technological changes in logistics. A new institutional and market direction in the development of supply chains and product distribution systems is being formed, which has important distinctive features:

1. The configuration of supply chains and the methods of commodity-marketing cooperation of commodity producers and real estate, which is becoming virtually autonomous, are changing.

2. The growing concentration of capital in the field of commodity circulation, its rapid infrastructural and technological development lead to the autonomization of sales, which in the future excludes the possibility of building vertically integrated value chains in the sense in which this concept is traditionally interpreted.

3. Operationally and technologically more complex multi-channel supply chains are emerging, in which logistics is actually a primary component of the product and service offer. It is quite possible that this is a consequence of the immaturity of the initial stage of the development of multi-channel sales, when many tasks in the context of a radically new shopping experience and behavior model in various channels led to the setting of a number of logistical tasks that are solved within the framework of existing technologies and IT solutions.

All this makes it possible to form a system of parameters for the comparative characteristics of single-channel and multi-channel supply chains, which is presented in table 2.12.

Table 2.12 – Comparative features of mono-channel and multi-channel supply chains in the consumer market product supply system

Comparison parameter	Monochannel chains	Multichannel chains
Market stability	low The margin is unevenly distributed among many links. During crises, the added value is reduced, part of the links are removed from the chain, causing its destruction	High The supply chain is short(direct sales system). The added value is optimal. During a crisis, chains grow even faster due to price advantages and optimal cost levels
Logistics as part of the sales business model	Logistics performs a supporting function and is not part of the business model. The growth of added value occurs in numerous links of the chain.	Logistics is a relevant part of the sales business model. It provides cost reduction, which is a necessary condition for the existence of online retail.
Functioning efficiency criterion	Minimum costs	Maximum economic effect, value proposition
Price level	High.	Low. Ensure a lower level of prices at the exit from the chain.

Level of added value	High	Low
Innovations and technologies, their role	Low level of innovation	High level of innovation
Institutional structure of trade and logistics links	Dominance of trade networks. Highway logistics and supply of goods to retail outlets.	The institutional structure of tradelogistics links are diverse: from online stores to marketplaces. Multi-link logistics: first mile, fulfillment, order processing; broadband last mile
Organizational and technological complexity of the supply chain	low	High The chain is more complex, various logistics of the last mile. Operational and technological docking of mainline logistics platforms - fulfillment - the last mile.
The role and importance of logistics.	average	High Logistics as a driver and relevant part of the product and service offer
Interaction of logistics and marketing in the chain	The importance of marketing is growing	Preservation of the parity of logistics and marketing in a complex system of omnichannel supply chains Expansion of marketing functionality in the

		mechanisms of purchase loyalty formation
A model of purchasing behavior	High level of purchase loyalty in off-line.	Low level of retailer loyalty. The buyer uses from 3 to 7 channels to search for and purchase the product
Market power parity in supply chains.	Low	High. Trade is becoming dominant in the supply chain
Economic features of the market development cycle	The growth of the market and final demand, the increase of added value in the chain and the asymmetric shift of the center of its accumulation to trade. The growth of currency and market risks in retail trade, their translation into the final price of the product.	Tougher competition, price pressure. Crisis, reduced demand, the need to create a highly competitive offer and progressive customer experience.

Source: compiled by the authors ZA Shi S., Wang Y., Chen H., Zhang Q. Conceptualization of omnichannel customer experience and its impact on shopping intention: A mixed-method approach, International Journal of Information Management, Volume 50, 2020, 325-336.; Timoumi A., Gangwar M., Mantrala M.K. Cross-channel effects of omnichannel retail marketing strategies: A review of extant data-driven research, Journal of Retailing, Volume 98, Issue 1, 2022, 133-151.

The results of the comparison show that multi-channel chains are a functionally and organizationally more perfect type of supply chains that meet the requirements of the modern market as much as possible and allow to form an adequate product offer in the network of relevant sales channels. From the point of view of logistics, marketing, chain configuration, the level of operational management of product and information flows, end-to-end management of the supply chain and stocks in sales channels, interaction with product manufacturers, multi-channel sales, in fact, is a new evolutionary step in the development of the consumer market product supply system.

Under such conditions, the structure of the "supply chain" system is determined by the composition of its links – entrepreneurs, enterprises, organizations and their divisions; - the level of their presence in the system - and the connections between them.

In fig. 2.18 Schematically shows the composition of the extended supply chain, which has a three-level structure.

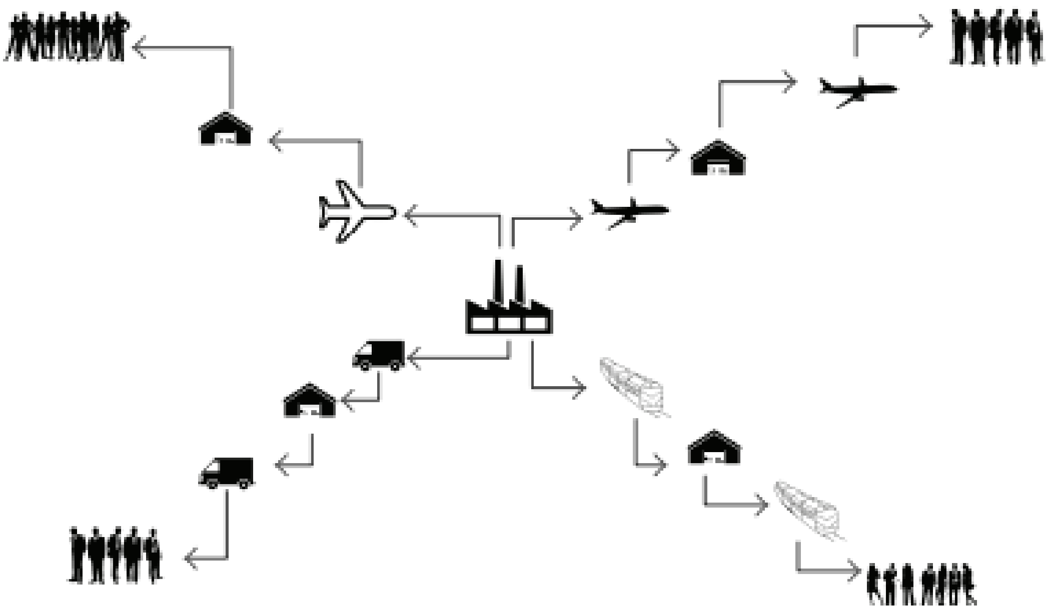


Fig. 2.18 Three-level supply chain

Source: compiled by the authors

For ease of description, we will display it in the form of a graph (Fig. 2.19).

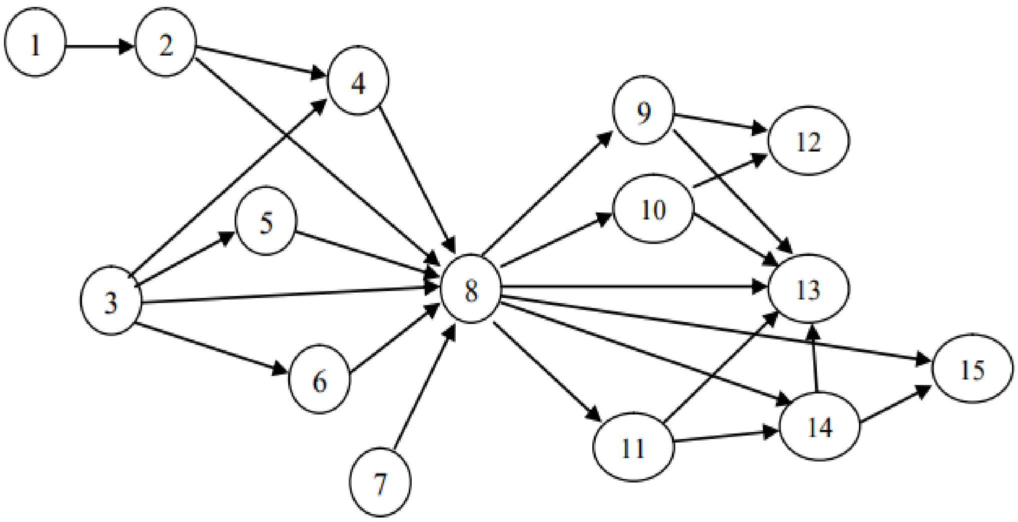


Fig. 2.19 Network model of the supply chain

Source: compiled by the authors

In the figure shown in Fig. 2.19 of the supply chain, the focal company (link 8) receives material resources from three suppliers (links 1, 3, 7).Moreover, supplier No. 1 works through intermediaries, supplier No. 3 works through intermediaries and directly, supplier No. 7 provides direct supplies. Enterprise No. 8 sells goods using both direct and indirect channels. Divisions 9, 10, 11, 14 act as sales intermediaries. Consumers are marked with numbers 12, 13, 15.

Unlike the classical model, the management of this model is characterized by some features, namely:

– the main elements of the supply chain are links and material flows;

– the goals of the networks differ;

– in the network model of supply chains, a central link and sub-networks are distinguished;

– a dynamic management model is developed for a separate project, and the network model of supply chains is relatively stable;

– there is no concept of "critical path";

– the supply of one subnet is relatively independent from the supply of another subnet.

Under such conditions, the focal company's main task is to find such solutions, under which the central link either achieves its goals with minimal logistics costs, or maximizes profit from the planned volume of goods, taking into account market needs.

Forming a mathematical model of the problem of minimizing external logistics costs for multi-product supply chains, we will introduce some conventions, namely:

– separately consider the planned indicators of purchases, sales, costs for the left and right subnets of the supply chain;

– the size of the production program is equated to the plan for the sale of goods;

– suppose that material resources are purchased, and sold goods are sold at the same prices.

Then the planned need of the enterprise for the purchase of basic materials:

$$M_i = \sum_{i=1}^{m} R_{li} Q_i, \quad (2.46)$$

where: Rli – the consumption rate of the lth material for the ith part;

m – the number of item positions;

Qi – the number of parts, assembly units, necessary for the execution of the production program.

The planned number of parts, assembly units, component products is determined on the basis of the production (sales) plan, taking into account the use of parts and assemblies in the products.

$$Q_i = \sum_{j=1}^{n} P_j k_{ij}, \quad (2.47)$$

where: Pj - production (sales) plan of the jth product;

kij – applicability of the i-th detail in the j-th product;

n is the number of nomenclature items of goods.

Logistics costs associated with the purchase of material resources (costs of the left subnet of the supply chain) are:

$$Z_1 = \sum_{p=1}^{u} \sum_{l=1}^{t} Z_{lp}, \qquad (2.48)$$

where: Zlp – delivery costs of the lth material from the pth supplier;

u – number of suppliers;

t- nomenclature of materials.

The sales plan is determined on the basis of marketing research of target market segments according to the formula.

$$P_j = \sum_{k=1}^{s} P_{jk}, \qquad (2.49)$$

where: Pjk is the sales plan for the jth product of the kth segment;

s is the number of segments.

Logistics costs associated with the sale of goods (costs in the right subnet) are calculated according to the expression:

$$Z_2 = \sum_{k=1}^{s} \sum_{j=1}^{n} Z_{jk}, \qquad (2.50)$$

where: Zjk is the cost of supplying the jth product to the kth segment.

Then the objective function - minimization of the focal company's total logistics costs related to purchases and sales will be as follows:

$$Z = Z_1 + Z_2 \rightarrow min, \qquad (2.51)$$

The solution to this problem is the selection of suppliers of material resources and the volumes of these supplies, as well as the selection of links of the distribution network and the distribution of goods between them. And the efficiency indicators:

– network density –is defined as the number of active, undamaged channels divided by the total number of potential channels in the supply chain. After all, the number of active channels plays a vital role, which should also be taken into account. For example, consider the situation when the contract between two enterprises is terminated, but none of the objects is violated. In such cases, the size of the network cannot accurately reflect its resilience if only the number of healthy nodes is considered. It is definitely necessary to take into account only active (active) channels;

– the size of the largest connecting component – during a failure, the supply chain can split into several isolated sub-networks. The size of the largest connected component serves as a criterion for quantifying the degree of fragmentation within the network. The larger size of the binding component indicates better functionality and less impact of failures on the overall supply chain;

- the maximum degree of centralization is another performance indicator that reflects the efficiency of the supply chain during disruptions.In the process of destruction. The maximum degree of centrality decreases as the connection between objects gradually disappears. Eventually, during recovery, it increases and reaches the original and standard level.

However, the stability, security and stability of the state of the supply chain depend on the coordinated (ideal) operation of all elements that make up its composition. A "perfect order" model of supply chain reliability typically includes three failure criteria:

- untimely execution of the order;
- the number of orders that are not completed in full;
- the number of improperly executed documents.

Therefore, reserve elements are introduced into such models "in parallel" with elements whose reliability is doubtful.

$$P_0 = \prod_{i=1}^{n} P_i = P_1 \times P_2 \times P_3 \ldots \times P_n \tag{2.52}$$

The number of reserve elements in the system is determined separately for each case, for example in R.Ballow[26] there are five of them. Also, when forming a multi-product order, it is recommended to use the WAFR formula (weighted average rating factor)

[26]Ballou RH Business Logistics/Supply Chain Management: Planning, Organizing and Controlling the Supply chain. 5th Edition, Pearson/Prentice Hall Inc., New Jersey, 2004, 789.

$$P_0 = \sum \omega_i \times P_i \quad (2.53)$$

where: wi – the weighting factor for the ith nomenclature;

Pi – the probability of error-free formation of the ith nomenclature of the order.

However, taking into account the complexity and stochasticity of the processes and the variety of optimization goals, building a reliability model for solving specific planning problems can only investigate a part of the overall supply chain and related costs.

Considering the fact that the ultimate goal of logistics is to reduce costs for logistics services and predict the probability of system failures, the concept of reliability for transport and logistics processes involves the delivery of cargo within a specified time, its security, safety and the adequacy of accompanying documents.

The number of tasks to optimize logistics processes in supply chains from the point of view of increasing its reliability is extremely large, and their composition is diverse. Therefore, in order to save resources, any economic entity should correctly build a system of restrictions on the resources used and key factors affecting reliability at any level of the supply chain. For example, the task of planning deliveries taking into account the functional reliability of carriers consists of the following steps[27]:

1. Construction of a functional diagram of the supply chain, indicating all carriers of the 2nd level and their characteristics.

2. Defining the concept of refusal and establishing the value of the criterion based on the functional capabilities of the carriers based on the customer's requirements.

[27]Ghorbani M., Ramezanian R., Integration of carrier selection and supplier selection problem in humanitarian logistics, Computers & Industrial Engineering, Volume 144, 2020, 106473

3. Compilation of a series-parallel scheme and a model for calculating structural reliability based on the requirements for uninterrupted supply and the functional capabilities of carriers.

4. Determination of the optimal supply plan, which ensures the minimum costs for compliance with requirements for non-failure.

At work[28] an outsourcing planning model is given, where for the customer, the task of forming a supply network turns into the task of choosing the channels with the lowest costs, provided that the requirements for parameters and failure are met. At the same time, it is noted that outsourcing to a third party can work effectively only when the external coordinator can ensure a low cost of knowledge transfer in the supply chain.

Under such conditions, reliability can be determined by the formula of the simplest parallel-serial scheme:

$$1-\prod_{i=1}^{m}(1-\prod_{j=1}^{n}P_j)\geq P_0; \quad if X_{ij}\geq 0 \qquad (2.54)$$

where: n – number of channels (providers);

m – the number of supply chains.

Here, the reliability of the system is ensured by backup elements included in it "in parallel" with those elements whose reliability is insufficient. Such models are usually supplemented with cost-limiting conditions for system operation.

Accordingly, the mathematical model of such a task has the following form:

$$S(X)=\sum_{i=1}^{m}\sum_{j=1}^{n}X_{ij}\times Z_j\times C_j; \qquad (2.55)$$

subject to restrictions:

$\sum_{i=1}^{m}\sum_{j=1}^{n}X_{ij}\times Z_j=Q_0$; requirements for volumes of supplies

$\sum_{i=1}^{m}X_{ij}\times Z_j\leq q_j$; $j=1,n$requirements for the capacity of supply channels

[28]Lu Q., Meng F., Goh M. Choice of supply chain governance: Self-managing or outsourcing?, International Journal of Production Economics, Volume 154, 2014, 32-38.

$1 - \prod_{i=1}^{m} \left(1 - \prod_{j=1}^{n} P_j\right) \geq P_0;\ if X_{ij} \geq 0$ requirements for uninterrupted supply

$Z_j \geq d; \quad j = 1, n$ requirements for the minimum order volume

where: Zj is the optimal plan of the jth supply channel;

Cj is the cost of the jth supply channel;

Qj – the volume of the jth supply channel;

qj is the possible volume (power) of supplies through the jth channel.

In this model, the objective function determines the most profitable chain at the minimum cost, in which a network of m supply chains with a series-parallel scheme of structural reliability is formed from n channels.

The optimal supply plan is the result of solving the problem of mathematical programming, where the reliability of the network channel is included in the optimization plan, then the objective function of the system can be written in the following form:

$$S(X_0) = \sum_{i=1}^{m\Sigma} \sum_{j=1}^{n\Sigma} (1 - \prod_{j=1}^{n} P_{ij}) X_{ij} \times Z_j \times C_j \rightarrow min; \qquad (2.56)$$

Under similar restrictions as in the previous formula.

This approach makes it possible to solve the problem not only of ensuring the necessary uninterrupted supply with minimal costs, but also to choose a chain of channels with the highest reliability. This model is one of the directions in the development of supply planning optimization models, taking into account the reliability (failure) of the execution of strategic plans and the definition of supply chains with high reliability.

However, given that a supply network can consist of channels with different characteristics, a structural reliability network model will typically include channels consisting of individual suppliers and supply chains or even entire sub-networks with a relatively complex (fractal) structure.

Fig. 2.20 shows that in order to ensure the given probability of failure-free operation of the supply chain P0, it is necessary to create a network of n channels by analyzing suppliers on the market and evaluating their potential functionality. These providers, in turn, can build level 3, 4 and higher level networks based on the same principles to ensure their own probability of failure-free operation p1, p2,... rn.

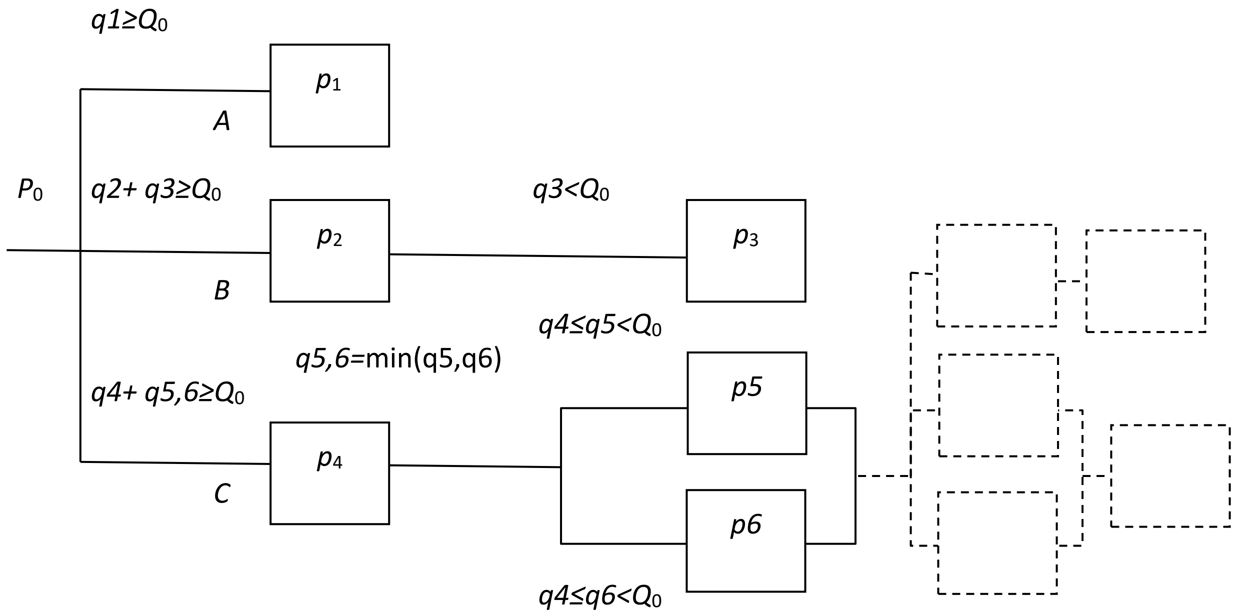


Fig. 2.20 Multilevel model of structural reliability of the supply network
Source: compiled by the authors

Accordingly, for the customer, the problem of building a supply network turns into the problem of choosing the most economically reliable channel that meets the requirements for functional parameters (such as fail-safe performance, determined using the formula forserial-parallel supply chain structure):

$$P_0 = 1 - \prod_{i=1}^{m}(1 - \prod_{j=1}^{n} p_j)_i, \quad m \le n, \quad if x_{ij} not \quad 0, \qquad (2.57)$$

where: n – the number of suppliers,

m – the number of supply chains (channels), *xi, j* – a binary variable (variable of choice) that takes the value 1 if the capacity of the j-supplier included in the i-th supply channel allows to satisfy the demand, 0 if it does not$\sum_{o=1}^{n} q_j x_{ij} \geq Q_0 \sum_{o=1}^{n} q_j x_{ij} \leq Q_0$.

A binary variable is used to form m chains from n channels.

Considering the reliability model of a complex network, in this case a series-parallel structural supply network (see Fig. 2.21), we cannote that in this case, for n = m, the model of the structural reliability of the supply network consists of n parallel-connected channels with a capacity of $q_j \geq Q_0$.

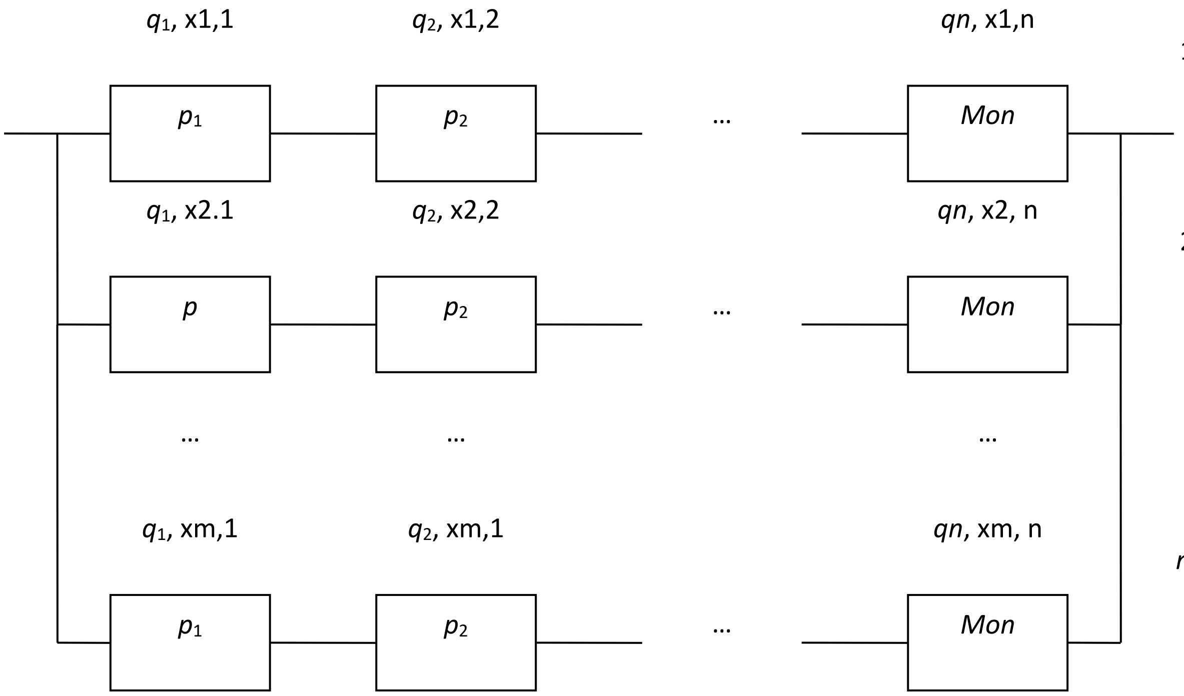


Fig. 2.21 Serial-parallel model of structural reliability of the supply network

Source: compiled by the authors

Which makes it possible to use the logical-probabilistic method of analysis for the formation of multi-level complex-structured models of the supply network. To do this, we will introduce variables representing the amount of product supplies from the jth supplier included in the ith supply channel. Then the optimal supply plan is determined as a result of solving the problem of mathematical programming with the objective function:

$$S_0 = \sum_{i=1}^{m} \sum_{j=1}^{n} c_j z_{i,j} x_{i,j} + \sum_{j=1}^{n} R_j x_{i,j} \to min, \tag{2.58}$$

subject to restrictions:

$$1 - \prod_{i=1}^{m} (1 - \prod_{j=1}^{n} p_j)_i \geq P_0 \, if x_{i,j} not \rightleftarrows 0; \tag{2.59}$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} z_{i,j} x_{i,j} = Q_0; \tag{2.60}$$

$$0 \leq \sum_{i=1}^{m} x_{i,j} \leq 1, \; j = 1, ..., n; \tag{2.61}$$

$$\sum_{i=1}^{m} z_{i,j} x_{i,j} \leq q_j, \rightleftarrows j = 1, \ldots, n; \tag{2.62}$$

$$\sum_{i=1}^{m} z_{i,j} \geq d, j = 1, \ldots, n; \tag{2.63}$$

$$\sum_{j=1}^{n} q_j x_{i,j} \geq Q_0 if x_{i,j} not 0 \rightleftarrows, i = 1, \ldots, m; \tag{2.64}$$

$$z_{i,j} \geq 0, i = 1, \ldots, m, j = 1, \ldots, n; \tag{2.65}$$

$$z_{i,j} \in R, i = 1, \ldots, m, j = 1, \ldots, n; \tag{2.66}$$

$$x_{i,j} \in \{0,1\}, i = 1, \ldots, m, j = 1, \ldots, n. \tag{2.67}$$

The objective function (2.58) is the sum of variable and fixed costs in this supply management system.

In the system of constraints, constraint (2.59) is a requirement for fail-safe supply chain consisting of series-parallel elements. The condition means: if $if x_{i,j} not 0 x_{i,j}$ not 0, then the value is used in the product. Otherwise, it is not included in the product, that is, only the probabilities of the channels included in the chain are multiplied.$p_j p_j$

Constraint (2.60) - supply volume requirement: a standard limit on the total supply volume across all channels of the network Q_0.

Constraint (2.61) – the condition that a supplier is included in one channel (one chain) means that the supplier can enter only one channel or none of them (redundant channel).

Restriction (2.62) is a restriction on the supply of suppliers q_j.

Limitation (2.63) is a limitation of the minimum order d, which takes into account the costs associated with concluding a supply contract, that is, it is an economic condition of the contract.

Constraint (2.64) is a condition for the formation of a supply channel: each channel must supply a volume of at least$Q_0 x_{i,j}$ not 0. Finally, constraints (2.65)-(2.67) indicate that the variables$z_{i,j}$ are nonnegative real numbers, and are Boolean variables $x_{i,j}$.

This model ensures the flexibility of the supply chain with a specified fail-safe due to the possibility of regulating the supply volumes by channels. At the same time, a number of problems arise when solving such a task. Firstly, it is the complexity of calculating the probability of fault-free operation of the supply network P_0, which requires the use of the logical-probabilistic method, i.e. descriptions of all operational and non-operational states of the supply network using Logical Algebra (LAL) functions, and secondly, the complexity lies in the large number of possible functional states of the system, especially in multi-level supply networks.

CHAPTER 3
APPLICATION OF ECONOMIC AND MATHEMATICAL MODELS FOR SUPPLY CHAIN RELIABILITY ASSESSMENT IN CONDITIONS OF UNCERTAINTY

When using economic-mathematical models, it is usually assumed that their parameters are deterministic. However, in practice, many of them are difficult to obtain accurately, which leads to uncertainty of the parameters. Based on various theoriesL. Chen, T, Dong, J. Peng and D. Ralescu[1] every one Uncertainty methods are divided into three categories:

1. Uncertainty programming based on probability theory. Here, the outcome of a random event cannot be determined before it occurs. However, this could be any of several possible outcomes. The actual result is assumed to be determined by chance.

2. Uncertainty programming based on the theory of fuzzy sets. This method considers the researched object and reflects its fuzzy concepts as a certain fuzzy set, establishes the corresponding membership function and analyzes the fuzzy object in the form of corresponding operations and transformations of the fuzzy set. The theory of fuzzy sets is based on the fuzzy mathematics of the study of phenomena related to imprecision.

3 Uncertainty programming based on uncertainty theory. Data based on the trust of experts refer to the subjective judgments of different experts about the probability of the occurrence of an uncertain event. Such considerations differ from the random sampling studied in classical statistics. The theory introduces uncertain variables to describe uncertain phenomena by establishing a new axiomatic

[1] Chen L., Dong T., Peng J., Ralescu D. Uncertainty Analysis and Optimization Modeling with Application to Supply Chain Management: A Systematic Review. Mathematics 2023, 11, 2530. https://doi.org/10.3390/math11112530

framework that mainly includes measures of uncertainty, uncertain variables and their distributions, as well as inverse distributions and applications.

The difference between these three approaches to uncertainty is that both probability theory and uncertainty theory attempt to model the level of human belief: the former uses tools to measure possibilities, while the latter uses tools to measure uncertainty[2]. However, fuzzy set theory (fuzzy logic), on the other hand, believes that the degree of confidence is a subjective probability or fuzzy set.

3.1 Application of reliability assessment models in supplies

Maintaining and developing the competitive advantages of supply chains is facilitated by the application of the security criterion. If security is a state of protection of an organizational and economic object from excessive danger, then the term "danger" implies the distribution of all undesirable events or processes (combination of dangerous factors). The specified events or processes may lead to disruption of the process of normal operation of the supply chain and deterioration of product quality, violation of delivery conditions and loss of profit. Multiple repetition of deviations, and sometimes one-time events, depending on their severity, can lead to the collapse of the "destruction" of the entire chain[3].

The cost-effectiveness of supply chains is determined by production costs, internal and external transportation costs, costs related to product quality (damages from insufficient quality levels, lost sales, product returns, etc.), handling and warehousing costs, and costs related to procedures orders Thus, the focus of the research was on the reliability of planning the need for material and technical resources, the reliability of suppliers and the reliability of the order and procurement management system, which refer, respectively, to the second, third and fourth stages of the functional cycle of supply logistics. Based on this, reliability management

---

[2]Cheng L., Rao C., Chen L. Multidimensional knapsack problem based on uncertain measure. Scientia Iranica Trans. E Ind. Eng. 2017, 24, 2527-2539.

[3]Lloyd DK, Lipov M. Reliability: organization of investigations, methods, mathematical apparatus. Moscow: Sov. radio, 1964. 699.

consists in choosing one or another tool that allows in specific conditions or for a specific business process to achieve the set goal. For example, if the goal is to increase the reliability of the supply chain, then the most effective tool for increasing reliability will be redundancy of business processes in supply chains (virtual, physical and time-based). At the same time, to reduce production and logistics costs, it is necessary to use rather complex planning methods based on operations research, and to increase safety - risk management methods.

However, inventories of raw materials, work in progress, and finished goods play a central role in optimizing the impact of production and resource allocation decisions made in each period throughout the planning horizon. Accordingly, the model must simultaneously determine the optimal random plan for each scenario and the optimal warning plan that differs from all random plans. Optimization involves the maximization (minimization) of expected revenues (costs), where the term "expected" means multiplying the profits (incomes) of each scenario by the probability of their occurrence. Within the framework of using the linear programming model of supply chain optimization, the most general task of production planning, which takes into account the dynamics of demand, production and storage of products, can be described as follows:

$$\sum_{j=1}^{n\Sigma} C_j \times X_j \rightarrow max \tag{3.1}$$

subject to restrictions:

$$\sum_{j=1}^{n} a_{ij} \times x_j \le b, \quad i = 1...., m; \; x_j \ge 0, \quad j = 1, ... n, \tag{3.2}$$

where: n – the number of products produced;

m – the number of used production resources;

a_{ij} – the volume of expenditure of resource "i" for the production of a unit of product "j";

c_j – profit from the production and sale of a unit of product "j";

b_i – amount of available resource "i";

x_j – volume of production of product "j".

However, in order for the supply chain planning process to be as effective as possible, it is necessary to have a clear idea of what and how to achieve the final result, that is, some "ideal" model that already exists and is used for the management of other supply chains must be proposed (methodology of using the best practice), or designed in "laboratory" conditions, the parameters of which must be achieved.

It is quite difficult, if at all possible, to fully implement the "ideal" model in practice. This is explained by the fact that it is impossible to accurately reproduce all those conditions in which the "ideal" model functions for another supply chain, and even more so it is impossible to implement an artificial "ideal" model created in laboratory conditions, because in this case it cannot be taken into account all real parameters of the market economy.

The problem of choosing an adequate method of managing the reliability of supply chains is that for the participants of the supply chain, all three main properties of an effective supply chain - reliability, economy and safety - are equally relevant. Therefore, it is necessary to jointly use the tools of reliability theory, planning methods based on operations research and risk management methods to ensure high performance of the supply chain. An example of the joint use of reliability theory tools and planning methods based on operations research is a methodical approach to the development of a supply chain topology based on the criteria of reliability and minimum costs[4]. Such a model expresses actualmultilateral relations between producers, who are integrated into a single system of exchange, and consumers. Accordingly, the supply chain can be effective only when all enterprisesparticipants are in normal condition[5]. It is obvious that the attractiveness of the supply chain for the consumer is determined by a certain level of reliability, which has

[4]MacCarthy B., Ahmed W., Demirel G. Mapping the supply chain: Why, what and how?, International Journal of Production Economics, Volume 250, 2022, 108688.

[5]Zhang M., Chen J., Chang SH., An adaptive simulation analysis of reliability model for the system of supply chain based on partial differential equations, Alexandria Engineering Journal, Volume 59, Issue 4, 2020, 2401-2407.

competitive advantages over the reliability of similar supply chains present on the goods (services) market[6].

Therefore, both for participants and for consumers, the quality of the supply chain is associated with a certain specified (expected) criterion of reliability, which depends on condition (3.1), in which nreliability means the probability of performing the necessary functions in a certain time interval. That is, it is a set of such criteria as: efficiency of order fulfillment from the point of view of compliance with delivery terms; quality of services provided; range of products; total costs. From these positions O. Mountain[7] proposes to conduct a multi-cretorial othe price of the supplier's activity according to 17 indicators in a point discrete scale (low score – 1–3 points, average score – 4–7 points, high score – 8–10 points), summarization is either the sum of points or a graphical interpretation in the form of building a logistics profile supplier It includes the following criteria for identifying the supplier's reliability assessment (Table 3.1):

Table 3.1 - Vendor Evaluation Criteria and Identifiers

1. Evaluation of the supplier's interest in the development of partnership relations

low	average	high
Demonstrates low interest in establishing a partnership. Does not distribute informationabout production costs	Takes certain steps to improve relationships. Informs about the development of the company	Appreciates long-termrelationships Significant interest of management at the highest level. Willingness to share long-term plans

2. Evaluation of supplier prices compared to market prices

low	average	high

[6] Zagurskiy O.Systematic and evolutionary approach to market research.Economic Annals-XXI, 2014, 11-12, 8-11.

[7]Girna, O. Supply chain: assessment of supplier reliability. Economy and society, 2022. (41). https://doi.org/10.32782/2524-0072/2022-41-39

Much higher than the market price	At the market level	Below the market

3. Evaluation of the supplier's initiative to reduce costs

low	average	high
Few ideas about cost reduction are put forward, the actual results of the initiatives are low. There is no desire to lower prices	Numerous proposals are put forward and it is possible to save 2–3% of the amount of annual expenses	Measures to reduce costs are constantly being planned, research into the possibilities of using alternative options is supported. It is possible to save 5% of the amount of expenses per year

4. Comparison of order fulfillment time with average terms for the industry

low	average	high
Long terms. Weak reaction to critical remarks	Average term. The provider has no plan to improve its situation. Responds to criticism	Terms are lower than those of competitors. Continuously takes measures to reduce them. High readiness to respond to loving criticism

5. *Evaluation of the supplier in making defect-free deliveries*

low	average	high
There are cases of detection of defects. Some defects appear repeatedly	Individual cases of detection of defects that do not lead to serious losses. There are no signs of systematic defects	Complete absence of defects

6. *Assessment of the supplier's ability to eliminate the causes of customer complaints*

low	average	high
Five or more appeals. Constant identification of cases of customer dissatisfaction	No more than two appeals. Individual cases of detection of isolated problems	No complaints

7. *Evaluation of the supplier's response to quality-related issues*

low	average	high
The supplier practically does not deal with quality issues. Can eliminate symptoms not reasons	The supplier investigates quality issues, but lacks responsiveness and determination	Immediate in-depth study of the problem. Effective corrective actions. An offer of appropriate compensation

8. *Evaluation of the supplier's certificates of conformity*

low	average	high
In certificatesthere are a number of omissions. Certificates are presented late It is superimposedadditional payment	Certificates are usually in satisfactory form or not required. Sometimes it is necessary to make additional efforts to obtain them. No additional payment is made	Certificatesare in perfect order and present themselves on time. No additional payment is made

9. *Evaluation of the quality of accompanying documents*

low	average	high
Missing important information. Poor design	Contains all basic information (product	Contains comprehensive information including lot

	code, order number)	number, lot weight, etc.

10.Assessment of the supplier's readiness for cooperation

low	**average**	**high**
The provider does not support the existing relationship scheme. There are many unresolved issues and current problems.	Attempts are being made to establish relations with production. Quick resolution of all issues	No questions about prices. Quick decision-making regarding discounts and credits

11.Evaluation of the effectiveness of the supplier's administrative system

low	**average**	**high**
A large number of questions on conducting prices. Discounts and credits all the time occur late	Real attempts to minimize price problems. Timely impact on price discounts and credits	No questions about prices. Quick decision-making regarding discounts and credits

12.Evaluation of the effectiveness of the supplier's sales department

low	**average**	**high**
Does not present required information by previously established dates. Has a bad idea about the status of the order in progress. Delays and problems when placing an order. Sometimes orders are accepted, which cannot be performed	Provides information about order fulfillment. Sometimes it takes a reminder. The orders that are received are quickly checked and the necessary actions are taken regarding their fulfillment	Timely presentation of all necessary information. Availability of accurate data on the status of each order. Only orders that can actually be fulfilled are accepted, otherwise alternative options are offered

14.Evaluation of the supply procedure

low	average	high
The supplier rarely makes a delivery notification. Cargo can arriveat any moment	The supplier makes advance notice of delivery, but the delivery schedule is sometimes disrupted	Alwaysa preliminary notice of delivery is made and the goods are delivered in the specified period

15.Assessment of the supplier's readiness to implement innovations

low	average	high
Priority is given to other buyers. Few new ideas	The supplier is readyto share some innovations. Provideracts in his own interests	Many innovations are introduced. The supplier is ready for close cooperation in work on research projects

16.Evaluation of the supplier's assistance in solving technical problems

low	average	high
weakreadiness to resolve issues. Low interest	The help that is needed is provided, but the resources to solve the problem are allocated reluctantly	Quick response to requestswhich arise by involving qualified assistance

17.Evaluation of the supplier regarding compliance with agreed work schedules

low	average	high
Lack of reaction. Samples, tools, finished goods often arrive late. An inflexible attitude is demonstrated	Sometimes there may be minor delays. Problems with adequate response to changes	Strict implementation of the agreed terms. Adequate response to changes

Source: Girna O. Supply chain: assessment of supplier reliability. Economy and society, 2022. (41). https://doi.org/10.32782/2524-0072/2022-41-39

According to the researcher, the wide application of the criteria makes it possible to most fully outline the negative elements in relations between enterprises that prevent the formation of long-term partnerships in the supply chain. In general, supporting the defined approach (the issue of the number of criteria remains debatable - in our opinion, it is more convenient to use 10), we note that its application can be more effective in strategic planning and supplier selection than in operational management.

However, the main obstacles to reliability in the supply system are random disturbances insupplies (deviation Xn from normal behavior X0.) These deviations correspond to changes in process parameters and/or results of interaction of supply chain elements. Moreover, the random variable Xn has a stable distribution characterized by the function (3.3)[8],and violations, as a result of the influence of dangerous (force majeure) factors, can be mutually compensated.

$$\varphi(X_n) = \{\exp\{-/\gamma w/[1 - isign(w)\beta\tan(\frac{\pi\alpha}{2}] + i\delta w\}, (\alpha \neq 1\} \qquad (3.3)$$

where: $sign(w) = \frac{w}{/w/}$, $\alpha \in (0.2)$

In the scientific literature, three general criteria for measuring sustainability are also widely used:

– recovery time – the time required for the supply chain to fully recover from a disruption[9];

- recovery level – the ratio of productivity after recovery to initial productivity[10];

[8]Nolan JP Modeling financial data with stable distributions. Department of Mathematics and Statistics, American University. 2005.105-130.

[9] Simchi-Levi D., Schmidt W., Wei Y. From superstorms to factory fires: Managing unpredictable supply chain disruptions Harvard Business Review, 92 (1–2) (2014), 96-101.

[10] Sawik T. A portfolio approach to supply chain disruption management International Journal of Production Research, 55 (7). 2017, 1970-1991.

- performance loss during recovery – shows the level of lost performance after recovery[11].

The biggest drawback of these criteria, according to G. Behzadi, M. O'Sullivan and T. Olsen's point is that each measures only one aspect (ie, ability) of resilience[12].

Thus, the impact of disruptions on supply chain interactions is always manifested through the reliability of suppliers.Accordingly, the main properties of supply chains from the point of view of their reliability are non-failure, economy and security of supply, and the main parameters of supply reliability are failure time, failure intensity, average recovery time, recovery intensity and probability of failure-free supply.

The listed indicators are taken in terms of dynamics or comparison, they fully characterize the supply process, they allow predicting the level of supply reliability and the duration of possible shortage situations.

The procedure for calculating the reliability of supply indicators for the exponential distribution of failure intensity is shown in Table 3.2.

Table 3.2 – Indicators of supply reliability under the exponential distribution of failure intensity and the order of their calculation

Indicator	**Calculation**
1. The time of delivery batch delays	$\Delta Tz = Df - Dpl$
2. The amount of undersupply	$\Delta V = Vpl - Vf$
3. Amount of average daily supply	$V=\sum V/T$
4. Conditional delay time in case of undersupply	$Tzp=V/v\Delta$
5. Total amount of delays	$\sum Tzp =\sum tzp +\sum t'zp$
6. Preparation for refusal of Tnv	$Tnv=(T-\sum Tzp)/p$

[11]Fang Y.-P., Zio E. An adaptive robust framework for the optimization of the resilience of interdependent infrastructures under natural hazards. European Journal of Operational Research, 276 (3), 2019, 1119-1136

[12]Behzadi G., O'Sullivan MJ, Olsen TL On metrics for supply chain resilienceEuropean Journal of Operational Research, 287 (1) (2020), pp. 145-158.

7. Failure intensity λ	λ=1/Tzp
8. Average recovery time	$Tv=\sum Tzp/p$
9. Recovery intensity	η=1/TV
10. Coefficient of availability (non-failure) supply Kg	$Kg=(T-\sum Tzp/T)$
11. Reliability of supplies in the provision of materials	$R = Kg \times e^{-\lambda c}$ $(0 < P \leq 1)$

Source: compiled by the authors

At the same time, we note that the indicator of supply reliability (P) is valid only for a one-time supply system, when one component product is supplied by one supplier. In other cases, the algorithm for determining the reliability of supplies may be as follows:

1) comparison of planned and actual delivery dates;

2) determining the time of delay;

3) comparison of the planned and actual volume of delivery, identification of cases of underdelivery of products;

4) determination of the volume of underdelivery of products:

$$\Delta Q = Q\text{actually} - Q\text{plan}; \quad (3.4)$$

5) definition of conditional lateness in case of non-delivery:

$$t' = \Delta Q : q, \quad (3.5)$$

where: ΔQ – amount of undersupply;

q – average daily consumption;

6) determination of the total amount of delays:

$$T_{\text{Op}} = t_{\text{Op}} + t'; \quad (3.6)$$

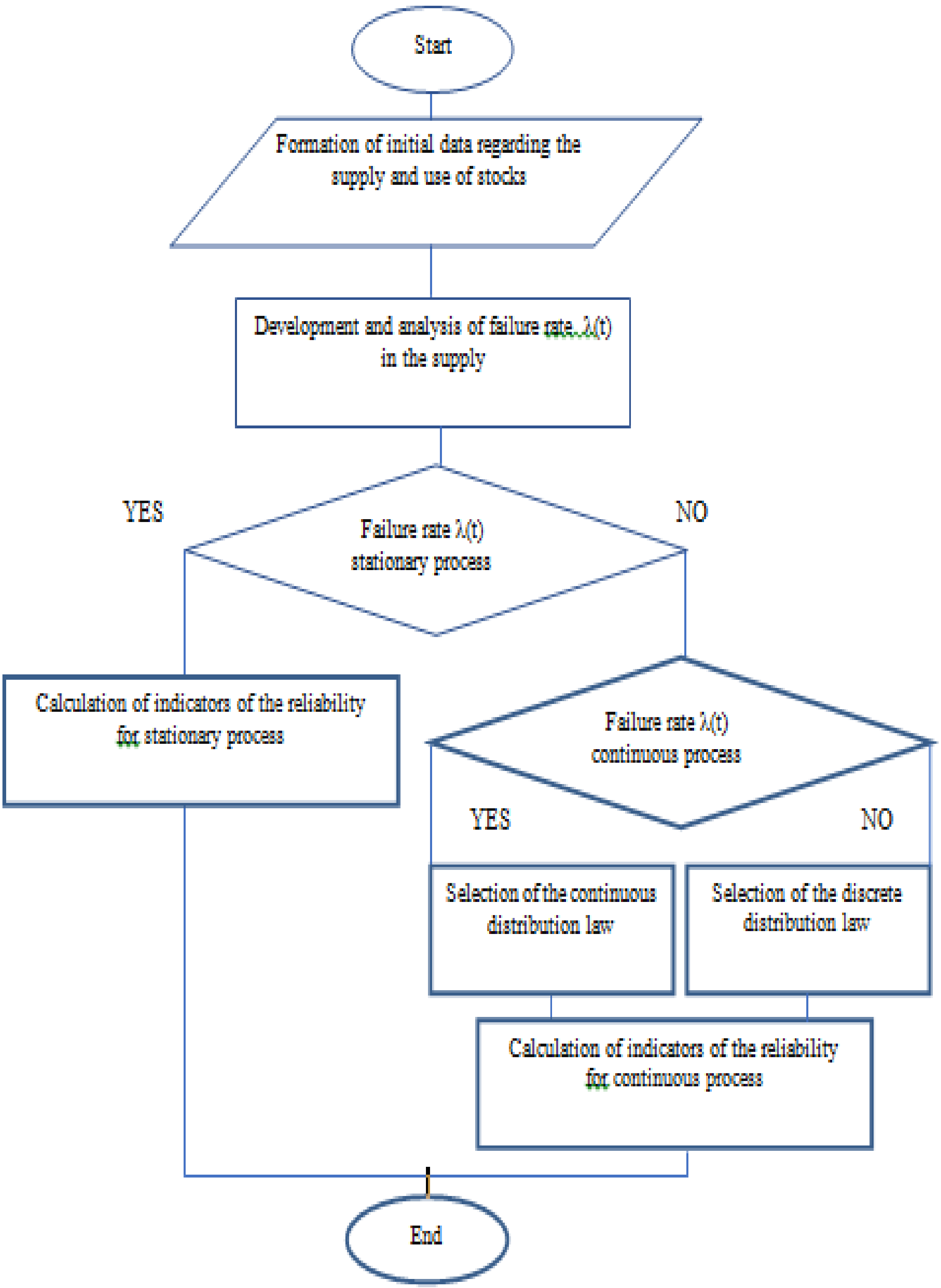
7) determining the number of cases of failure;

8) determination of failure time:

$$\text{T}_0 = \frac{T - \sum T_{\text{оп}}}{n} \quad (3.7)$$

where: T is the total number of days in the period;

And the algorithm for calculating the reliability of supplies in fig. 3.1:



Rice. 3.1 Algorithm for calculating supply reliability

Source: compiled by the authors

9) determination of failure intensity:

$$\pi = \frac{1}{T_{\text{оп}}} \tag{3.8}$$

10) determination of the supply availability ratio:

$$K_{\text{г.п}} = \frac{T - \sum T_{\text{оп}}}{T} \tag{3.9}$$

11) calculation of reliability of supply:

$$P = K_{h.p}\, exp(-\pi t). \tag{3.10}$$

And the higher the supply readiness ratio Kg.p, which characterizes the reliability of the supplier, the more reliable the supply chain. However, atthe development of supply reliability indicators must take into account the peculiarities of the supply process, namely:

− the intensity of supply failures λ(t), which can be both a stationary process and a non-stationary process (have trends, seasonality, random spikes), therefore, the calculation of the reliability of the supply chain can be both static and dynamic;

- failures in the supply of goods can be both continuous and discrete (for example, their dynamics can be attributed to rare events). Therefore, it is necessary to choose the best probability distribution law for the failure intensity function λ(t): continuous (exponential, normal, Weibull, gamma distribution) or discrete (Poisson, binomial).

For a normal distribution, the reliability function (fail-free operation) is calculated by the formula:

$$P(t) = \int_t^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{(x-m)^2}{2\sigma^2}} dx = 0.5 - \Phi_0(\frac{t-m}{\sigma} \tag{3.11}$$

where: t = Δt – interval length, days;

m = T_0 – average time between failures, days;

σ = σ_T – root mean square deviation of the time between failures, days;

$\Phi_0 = \frac{1}{\sqrt{2\pi}} \int_0^t e^{\frac{x^2}{2}} dx$ is the Laplace function, the values of which are summarized in the table.

At the same time, a number of conditions are taken into account:

– exceeding the size of the delivery batch against the planned one does not compensate for the violation of the delivery deadline;

- in the event that the delivery deadline is violated and there is underdelivery, two types of delay are considered: by date and due to underdelivery;

– if the delivery did not take place within the specified period, then in this case the conditional delay is determined by the entire volume of delivery of the undelivered lot;

– deliveries made before the planned deadline are considered to be made on time.

For example, the calculation of the reliability of the supply process is given based on the data of the supply chain of spare parts of the "Sfera-Avto" enterprise (table 3.3).

Table 3.3 – Calculation of the reliability of supplies provided with materials under the exponential distribution of the intensity of failures

Indicator	Value												∑ or average
Month of supplies	January	February	Mar	flower	May	June	July	sickle	September	October	letter	December	
The length of the interval Δt,	31	28	31	30	31	30	31	31	30	31	30	31	365

days													
Sum of interval lengths ∑Δt, days	31	59	90	120	151	181	212	243	273	304	334	365	
Delay tzp, days	0	0	5	10	17	13	0	0	3	0	16	15	79
Conditional delay t'zp, days	0	0	0	0	0	0	7	20	11	30	0	0	68
Total delay tzp+t'zp, days	0	0	5	10	17	13	7	20	14	30	16	15	147
The volume of supply is planned Vpl, kg	600	600	600	600	600	600	600	600	600	600	600	600	7200
Actual delivery volume Vf, kg	600	600	600	800	1000	640	460	200	380	0	720	1200	7200
Volume of product shortages ΔV, kg	0	0	0	200	400	40	-140	-400	-220	-600	120	600	0
Stock consumption intensity ν, kg/day	20	20	20	20	20	20	20	20	20	20	20	20	20
The number of failures n(t, t+Δt),	0	0	1	1	1	1	1	1	1	1	1	1	10
Working time for failure Tnv, days	31	28	26	20	14	17	24	11	16	1	14	16	21.8
Average TV recovery time,	0	0	5	10	17	13	7	20	14	30	16	15	14.7

days													
Failure intensity λ(t)	0.032	0.036	0.038	0.05	0.071	0.059	0.04	0.091	0.063	1	0.071	0.063	0.045
Readiness function Kg(t)	1	1	0.839	0.667	0.452	0.567	0.77	0.355	0.533	0.032	0.467	0.516	0.597
The idle function Kp(t)	0	0	0.161	0.333	0.548	0.433	0.23	0.645	0.467	0.968	0.533	0.484	0.402
The possibility of fault-free operation P(t)	0.968	0.965	0.807	0.634	0.420	0.534	0.74	0.324	0.501	0.012	0.435	0.485	0.570

Source: compiled by the authors

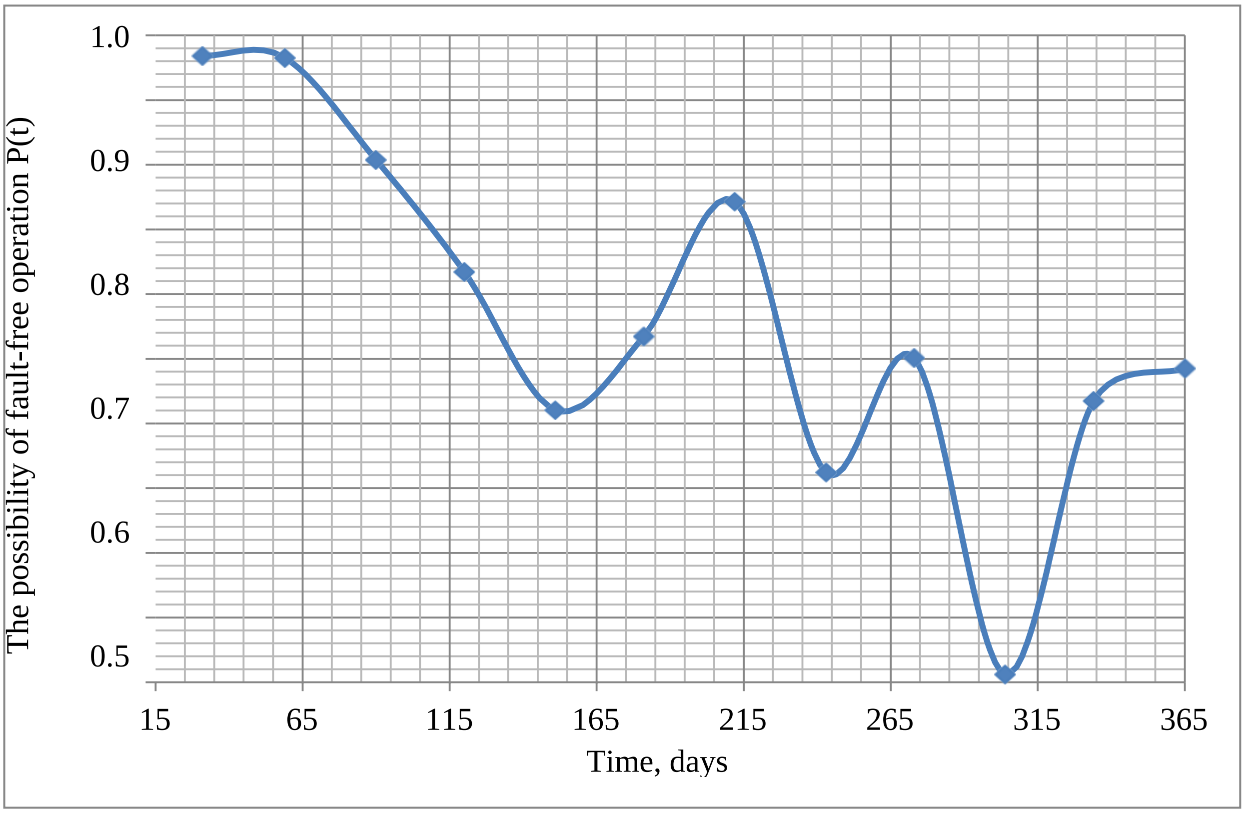


Fig. 3.2 Graphs of the dynamics of the change in the probability of failure-free operation P(t) with the exponential distribution of failure intensity

Source: compiled by the authors

In fig. 3.2 shows a graph of the dynamics of the change in the probability of failure-free operation P(t), which corresponds to the exponential distribution of failure intensity.

The analysis of the dynamics of changes in the intensity of failures $\lambda(t)$ (see Table 3.3 and Fig. 3.2) shows that the occurrence of failures is a non-stationary process, therefore, first, it is necessary to study the parameters of supply reliability in dynamics; secondly, the distribution of this indicator is sharp-edged, asymmetric, has a number of local extrema and does not agree well with the exponential distribution, therefore, to calculate the supply reliability parameter in the provision of materials for the supply chain, it is necessary to choose the most appropriate distribution law.

The assessment of the volume of undelivered goods ΔV shows that the supply problems at the enterprise began in July, when the volume of undelivered goods ΔV was 140 units, and reached a maximum in October, when there were no deliveries of goods, and $\Delta V = - 600$ units, therefore, the trade or the production process at this enterprise during the specified period of time could be interrupted due to the lack of the necessary material;

Analysis of the dynamics of changes in the readiness function Kg(t) and the idle function Kn(t) (see Table 3.3) shows that they change in a wide range throughout the entire planned time period T, and the readiness function Kg(t) reaches its maximum in January and in February, and the minimum in October, while the idle function Kp(t) has reverse dynamics;

The results of the calculation of the downtime function Kp(t) show that in August, October and November the enterprise could be idle for most of the time due to the lack of the necessary material. At the same time, the data given in Table 3.3 do not give an opportunity to answer the question of what value of the total delay top+t'op is critical, that is, it leads to the stoppage of the production or trade process, so it is necessary to know the value of the insurance stock in order to determine the unacceptable value of the total delay top+t'op;

Analysis of the dynamics of the change in the probability of failure-free operation P(t) with the exponential distribution of failure intensity (see Fig. 3.2) shows that this indicator changes in a wide range of values from 0.968 in January to 0.012 in October, the dynamics of this indicator fully correspond to the dynamics of the change in the readiness function Kg(t) (see Table 3.3), but differs somewhat from it in magnitude.

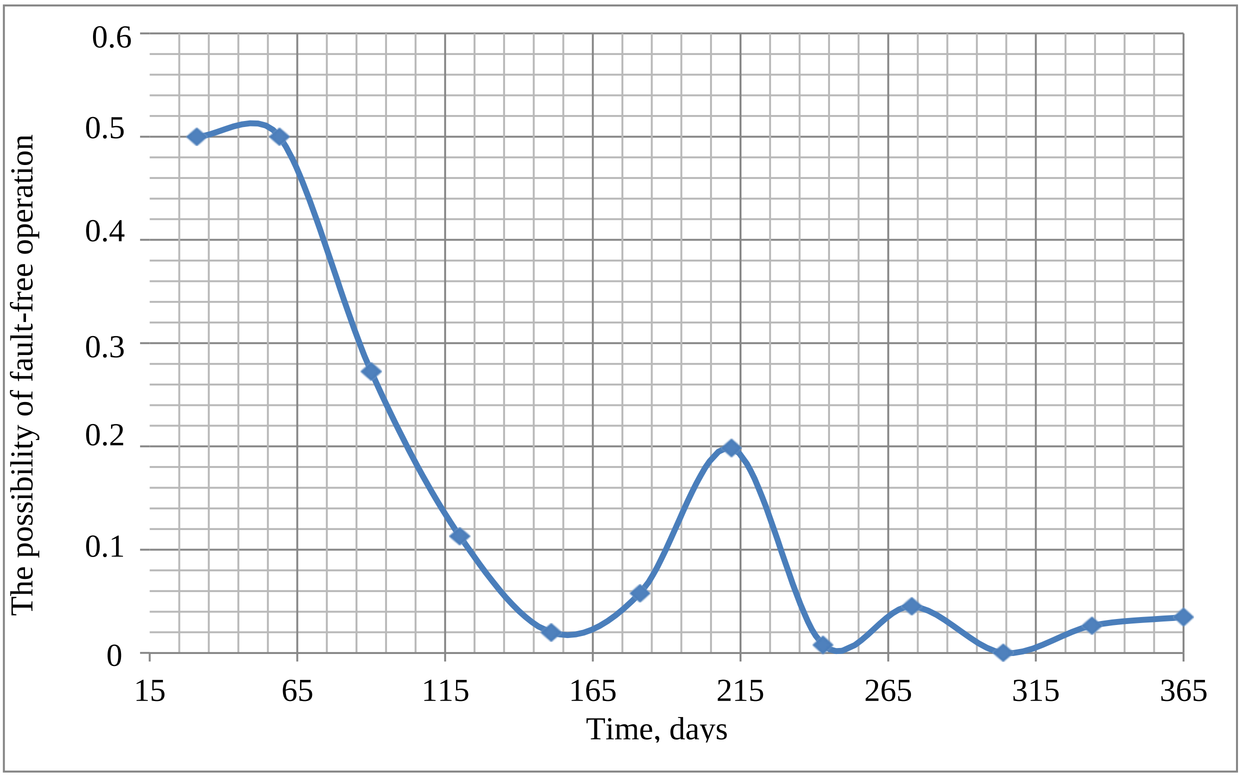


Fig. 3.3 – Graphs of the dynamics of the change in the probability of failure-free operation P(t) with a normal distribution of failure intensity

The assessment of the dynamics of the change in the probability of failure-free operation P(t) with a normal distribution of failure intensity (see Fig. 3.3) shows that the dynamics of this indicator corresponds to the dynamics of the change in the availability function Kg(t) and the probability of failure-free operation P(t) with an exponential distribution of failure intensity (see Table 3.3), but significantly differs from them in magnitude.

Thus, in the case considered by us, for the time interval Δt = 30.4 days, that is, on average for a month, the reliability function is equal to P(30.4)=0.149. It is obvious that the higher the value of the probability coefficient of fault-free operation P(t) characterizes higher reliability of supplies.

To ensure stable and efficient operation of the supply chain in a competitive environment, manufacturing enterprises must actively respond to changes in supply conditions, including supply chain design and recovery strategy.

3.2 Application of reliability assessment models inproduction and logistics systems

The approach that best meets the requirements for making managerial decisions in conditions of uncertainty is the cognitive approach, which is aimed at identifying dependencies and regularities of the reliability potential and behavior of the business entity. It is inherently based on both the economic system and human consciousness and takes into account both internal and external factors affecting the supply chain. That is, it simultaneously uses both SWOT analysis to determine the strengths and weaknesses of supply chain participants and PEST analysis to assess the external economic situation.

However, the effectiveness of such an analysis depends on the possibility of building an adequate system of unambiguous interpretation of the results of mathematical processing of a defined group of target indicators in order to prevent and avoid ambiguity of conclusions, contradictions in the views of individual experts regarding the identification of the state of the research object. To ensure an adequate translation of the quantitative value of the general indicator of the performance of the motor vehicle enterprise into a qualitative assessment, we used the so-called desirability function (Harrington scale)[13].

[13] Harrington ECJr. The desirability function. Industrial Quality Control, 1965. April. V. 21. No. 10. 494-498.

Table 3.4 – Characteristics of levels of investment potential

The value of the level of efficiency	Characteristics of level valuesinvestment potential
1.00 - 0.80	High levelinvestment potential
0.80 - 0.63	Average levelinvestment potential
0.63 - 0.37	Levelinvestment potentialbelow average
0.37 - 0.20	Lowinvestment potential
0.20 - 0.00	Unacceptable levelinvestment potential

Source: Harrington ECJr. The desirability function. Industrial Quality Control, 1965. April. V. 21. No. 10. 494-498.

The desirability function analysis procedure consists of three stages:

1. Selection of analysis parameters;

2. Obtaining parameter values;

3. Combining the obtained values into a generalized indicator characterizing the current level of investment potential as a whole.

The choice of specific methods and criteria for assessing the reliability of the supply chain depends primarily on the specifics of the situation and the needs of the customer of the analysis. We propose to use five groups of indicators as general criteria for an integrated assessment of the performance of motor transport enterprises.

1) economic potential of the supply chain (E);

2) technical potential of the supply chain (T);

3) organizational and intellectual potential of the supply chain (O);

4) information potential of the supply chain (I)

5) external conditions of supply chain functioning (Z).

Accordingly, the absolute value of the generalizing integrated indicator is calculated according to the formula:

$$Z=\alpha_E\times\sum_{i=1}^{n}\beta_i^E\times E_i+\alpha_T\times\sum_{i=1}^{n}\beta_i^T\times T_i+\alpha_I\times\sum_{i=1}^{n}\beta_i^I\times I_i+\alpha_O\times\sum_{i=1}^{n}\beta_i^O\times O_i+\alpha_Z\times\sum_{i=1}^{n}\beta_i^Z\times Z_i, \tag{3.12}$$

where: α_i – weighting factors of research directions;

β_i – weight coefficients of target indicators in separate areas.

Each group, in turn, is formed from the indicators of the group, which collectively meet the requirements of a comprehensive description of the current state of the enterprise and its development prospects from the point of view of the balance of development goals. At the same time, the use of a large number of indicators, on the one hand, can cause a loss of time for mathematical and analytical support for the study of functionally interdependent indicators, and on the other hand, in the absence of interdependence between them, lead to a large error in calculations. Therefore, it is suggested to use a reasonable (sufficient) number (3-4) of the main indicators that are closely correlated with each other.

The level of the enterprise's ability to achieve the defined potentials in groups is determined by the formula:

$$К_{М}^{i}=\frac{\sum_{1}^{n}Х_i\times\alpha_i}{n} \tag{3.13}$$

where: $Х_i$ – the level of the indicator;

α_i – the weight of the indicator;

n – the number of indicators within the corresponding component of the potential opportunities of the supply chain.

Moreover, here and further we assume by condition: the growth of a separate indicator Chi is connected with the growth of the efficiency of the considered supply chain. If an opposite trend is observed for this indicator, then in the analysis it should be replaced by a related indicator of the opposite value.

Each indicator Xi is compared with its level of significance for the analysis ri. To estimate this level, you need to arrange all indicators in order of decreasing importance so that the rule is fulfilled

$$r_1 \geq r_2 \geq \ldots r_N. \quad (3.14)$$

Ranking is done using the Fishburne rule[14]

$$r_i = \frac{2(N-i+1)}{(N-1)N} \quad (3.15)$$

To assess the reliability of the supply chain, we build a system of 15, in our opinion, the most important indicators.

Table 3.5 – Indicators of supply chain reliability

No p-ka	Indicator	Potential group	Group weighting factor	Calculation method
X1	coverage ratio	financial	4	formalized
X2	activity profitability ratio			
X3	equity ratio			
X4	coefficient of wear and tear of production facilities	technical	4	
X5	coefficientaverage daily production			
X6	coefficientlabor productivity			
X7	level of information support	informative	3	
X8	the number of sources of information			
X9	the number of consumers of information			
X10	level of business reputation	organizational and intellectual	3	informalized
X11	management level			
X12	the level of qualification of employees			
X13	the level of investment attractiveness of the regionin which the company operates	external operating	2	

[14]Fishburn R. Utility Theory. Management Science, Vol. 14, No. 5, Theory Series (Jan., 1968), 335-378.

X14	the level of development of market institutions in the country where the company operates	conditions of the enterprise		
X15	transport operating conditionsnaturally-the ecological state of the region			

Source: compiled by the authors

And if the indicators of the first three groups are calculated by formalized methods of describing analytical procedures based on clear dependencies from the use of the mathematical apparatus of economic and financial analysis, then the indicators of the last two take into account subjectivity, informalized dependencies are built on a logical level from the use of expert opinions and estimates, and therefore can be subjective.

It is possible to reduce the subjectivity of the indicators of the last two groups with the help of objective and structural approaches. In particular, those based on the rules of fuzzy logic[15].

The fuzzy multiple method uses linguistic quantities and expressions to describe the determined potentials of the enterprise and is ideal for planning factors at a time when their future assessment is blurred and does not have sufficient grounds of probability. The problem of deviations of the values of the cause or effect factors in the form of a fuzzy set is used in cases where the expert cannot accurately determine the deviation of the effect factor caused by the deviation of the cause factor. The membership function of the deviation value of the consequence factor is given by a fuzzy set:

$$\mu_{[0;1]}(X_s^r) = \{X_{s_1}^r/V_1, X_{s_2}^r/V_2, \dots, X_{s_n}^r/V_n\} \qquad (3.16)$$

where: $X_{s_1}^r, \dots, X_{s_n}^r$ – factor value after increase,

[15]Zadeh L.Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic.Fuzzy sets and systems, 1997.Vol. 90, No. 2,111-127.

V1,...,Vn – subjective estimates of the possibility of corresponding increases in the effect factor at a given increase in the cause factor.

According to the fuzzy multiple approach, a classification of the current values of X indicators is constructed as criteria for dividing the full set of its values into subsets of type B.

Table 3.6 – Classification of current values of X indicators

The name of the indicator	Criterion of division into subsets				
	B1	Bi2	V3	V4	V5
X1	x1<b11	b11<x1<b12	b12<x1<b13	b13<x1<b14	b14 < x1
…	…	…	…	…	…
XN	xN<bN1	bN1<xN<bN2	bN2<xN<bN3	bN3<xN<bN4	bN4< xN

Source: compiled by the authors based on the fuzzy-multiple approach.

Table 3.7 – Indicator level classifications

The name of the indicator	The result of classification into subsets				
	B1	Bi2	V3	V4	V5
X1	λ_{11}	λ_{12}	λ_{13}	λ_{14}	λ_{15}
…	…	…	…	…	…
XN	λ_{N1}	λ_{N2}	λ_{N3}	λ_{N4}	λ_{N5}
Weight (g)	0.1	0.3	0.5	0.7	0.9

Source: compiled by the authors based on the fuzzy-multiple approach.

Next, the current level of indicators is assessed and their values are classified, where $\lambda_{ij} = 1$, if $b_{i(j-1)} < x_i < b_{ij}$, and $\lambda_{ij} = 0$ in the opposite case (when the value does not fall into the selected classification range), and the obtained results are summarized in table 3.7.

After performing formal arithmetic operations to estimate the level of potentials g:

$$g = \sum_{j=1}^{5} g_j \sum_{i=1}^{N} r_i \lambda_{ij} \qquad (3.17)$$

We classify the received values of the degree of their levels in the database of table 3.8.

Table 3.8 – Classification of the current g value of the level indicator potential G

The interval of G values	The name of the subset
0.8 < g < 1	G5- extremely high level
0.6 < g < 0.8	G4- high level
0.4 < g < 0.6	G3- average level
0.2 < g < 0.4	G2- insignificant level
0 - 0.2	G1- extremely low level

Source: compiled by the authors based on the fuzzy-multiple approach.

Thus, our conclusion about the level of reliability of the supply chain acquires a linguistic form.

The developed approach generalizes the system of evaluation indicatorschain reliability and serves as a tool for determining its level. The procedure is based on the calculation of qualitative and quantitative indicators of reliability, the main tool of the proposed methodical approach is the desirability function, supplemented by the calculation of the integrated coefficient. The proposed integrated indicator of the level of reliability of the chain makes it possible to comprehensively approach the assessment of its activity and single out individual processes that need to be improved. The implementation of the developed measures will make it possible to increase the overall reliability of the chain and, accordingly, increase its investment attractiveness for potential investors.

For the practical application of the model of the reliability of the enterprise's production and logistics system and the choice of an alternative strategy, we will use the method of hierarchy analysis (HAI). The purpose of the method is to justify the choice of the best of the proposed alternatives, the characteristics of which are vectors with heterogeneous, including vaguely defined, separate components[16].

The essence of the method of analyzing hierarchies consists in the step-by-step solution of such interconnected individual tasks as:

– construction of a hierarchical structure of indicators;

– assessment of the significance of individual indicators for each level of the hierarchy;

- comparison of available alternatives and selection of the best of them.

This method appears to be simple, clear and convenient for calculations. Accordingly, it is widely used in practical activities to perform decision-making tasks in various settings: to choose the best one or several best options, to order (rank) all options according to their merits, etc.

The following advantages of using MAI can be distinguished in comparison with other methods of selecting alternative projects and determining priorities.

- uses a hierarchical structure and allows decision-makers to define the level of strategic objectives and specific indicators for a better assessment of strategic alignment.

- goes beyond the scope of financial analysis as a result of the integration of quantitative and qualitative parameters.

- enables decision makers to measure the relative importance of projects, including their benefits, costs, risks and opportunities, resulting in more efficient use of funds.

[16]Saaty TL The Hierarchon: A Dictionary of Hierarchies. Pittsburgh, Pennsylvania : RWS Publications, 1996. 510.

- can be applied in any organization with any level of maturity, as data is normalized using numerical estimates or expert judgment when the required metrics are not available.

- amenable to sensitivity analysis, which provides a greater number of analytical possibilities when considering one or another scenario[17].

To choose the principle of construction of the production and logistics system, we will assess the state of the enterprise and the possibility of implementing the system in the existing conditions. Based on the level of indicators, it is possible to draw a conclusion about which system, at a given moment, the conditions most fully meet its requirements. At the same time, we will evaluate the directions that the company needs to improve for further transition from one system to another.

Since the study of the company's indicators is carried out at the current moment in time, the solution to the problem will take place in conditions of certainty. Thus, we will build a model of linear programming of decision-making under conditions of certainty. There are many variants of the V system for this system

$$V = (V1;\ V2) \tag{3.18}$$

where: V1 – traction system,

V2 – pushing system.

Each option Vi is characterized by the values of the criteria Xi. That is, for each option there is a vector criterion X

$$X = (X1, \dots Xn) \tag{3.19}$$

where: n – the number of criteria,

Xi – a criterion that takes values from a set of Ni (scales).

The objective function in this case will be represented by an additive function:

[17]Kendrick JD, Saaty D. Use Analytic Hierarchy // Process For Project Selection. Six sigma forum magazine. 2007. 22-29. URL:http://engexecforum.com/external%20files/Use%20Analytic%20Heirarch%20for%20Project%20Selection.pdf

$$H(x) = a_1 n_1(x) + a_2 n_2(x) + \dots + a_m n_m(x) \rightarrow max \qquad (3.20)$$

where: a_i – the degree of importance of the criterion (its relative weight),

n_m (x) – the level of its value at the enterprise.

The whole set of n criteria considered should cover the key processes of purchase, production, consumption, which are important for both pulling and pushing systems.

We selected the following indicators as criteria that influence the decision to choose a production and logistics concept:

– reliability of the supplier – a particularly important criterion for a traction strategy in which the key place is occupied by suppliers and relations with them;

– availability of warehouse space is a criterion more characteristic of the push strategy, because unclear tracking of demand presupposes the mandatory availability of insurance stocks;

– fluctuations in demand – the criterion is typical for both concepts, but due to low flexibility, it has a greater impact on a push strategy where fluctuations in demand can lead to more negative consequences;

– pProductivityof labor – acts as a factor that has a great influence on both alternatives, because for the principle of extraction it ensures a short production cycle, and for pushing - the efficiency of the entire system, which is determined by the direct dependence of the volume of production and income;

– the quality of the produced products is also a factor that is important for both systems. The level of quality must be assessed both at the entrance to the production and logistics system and at the exit. Both factors are extremely important for the traction system. The lack of input control leads to increased responsibility of suppliers, and the lack of stocks makes the quality of manufactured products one of the priority tasks of production, because each unit of defective goods generates the need to create a buffer.

Moreover, taking into account the peculiarities of the first two criteria and their impact on production and logistics systems of various types, we will divide them into additional indicators 1 (kcoefficient of the volume of supplies, coefficient of timeliness of supplies, coefficient of quality of supplied materials; factor of remoteness of the supplier), 2 (factor of provision of area of storage of unfinished production, factor of provision of area of storage of finished products, coefficient of provision of area of storage of raw materials and materials). Thus, the system of indicators that influence the decision-making on the choice of a production and logistics concept has the following form.

Table – 3.9 System of indicators affecting decision-making when choosing a production and logistics concept

Indicator	Indicator	Partial coefficient	Integratedcoefficient
Reliability of the supplier	Coefficient of the volume of supplies	n1	N1
	Coefficient of timeliness of deliveries	n2	
	Quality factor of supplied materials	n3	
	Supplier remoteness factor	n4	
Security warehouse areas	Coefficient of security of the area of maintenance of work-in-progress	n5	N2
	Coefficient of provision of the area of storage of finished products	n6	
	Coefficient of security of the storage area of raw materials and materials	n7	

Fluctuations in demand	The coefficient of deviation of actual sales from the planned ones	n8	N3
Labor productivity	Performance level	n9	N4
Quality of manufactured products	Coefficient of quality of manufactured products	n10	N5

Source: compiled by the authors

The integrated coefficient of each indicator is calculated as a weighted average of partial coefficients.

$$N_i = \frac{n_1 + n_2 + \ldots + n_i}{i} \qquad (3.21)$$

The Ni coefficient shows the level of each of the indicators considered at this enterprise. Moreover, each ni indicator is assigned its level of significance for the Ni analysis. To evaluate this level, you need to arrange all the indicators according to the degree of their importance, so that the rule n1>n2>...ni is followed. Ranking occurs using the Fishburn rule discussed above (see expression 3.15).

And if we assume that the level of development of the production and logistics system of the enterprise is equal to 1, then the matrix "A" built using the method of pairwise comparisons will look like this.

$$A = \begin{pmatrix} 1 & \frac{N_1}{N_2} & \frac{N_1}{N_3} & \frac{N_1}{N_4} & \frac{N_1}{N_5} \\ \frac{N_2}{N_1} & 1 & \frac{N_2}{N_3} & \frac{N_2}{N_4} & \frac{N_2}{N_5} \\ \frac{N_3}{N_1} & \frac{N_3}{N_2} & 1 & \frac{N_3}{N_4} & \frac{N_3}{N_5} \\ \frac{N_4}{N_1} & \frac{N_4}{N_2} & \frac{N_4}{N_3} & 1 & \frac{N_4}{N_5} \\ \frac{N_5}{N_1} & \frac{N_5}{N_2} & \frac{N_5}{N_3} & \frac{N_5}{N_4} & 1 \end{pmatrix} \qquad (3.22)$$

Matrix "A" allows you to assess which indicators are more important at this enterprise. For this, the normalized matrix "A" is calculated by dividing the elements of each column of the matrix "A" by the sum of the elements of these columns.

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{21} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{pmatrix} \qquad (3.23)$$

Then, to determine the share of each indicator at the level of enterprise processes, we will find the average value of the row elements:

$$A = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{pmatrix} \qquad (3.24)$$

Assessment of the importance of processes for each of the systems is carried out taking into account the experience of specific enterprises. To do this, we will compile a pairwise comparison matrix (tables 3.10-3.11).

Table 3.10 – Matrix of pairwise comparison of the importance of indicators for the traction system

Indicator	Reliability of the	Security warehouse	Fluctuations in	Productivity labor	Quality of manufactured	In total
Reliability of the supplier	1	1	1	1	1	5
Availability of warehouse space	0	1	0	0	0	1
Fluctuations in demand	0	1	1	0	0	2

Labor productivity	0	1	1	1	0	3
Quality of manufactured products	0	1	1	1	1	4

Source: compiled by the authors

Table 3.11 – Matrix of pairwise comparison of the importance of indicators for the pushing system

Indicator	Reliability of the	Security warehouse	Fluctuations in	Productivity labor	Quality of manufactured	In total
Reliability of the supplier	1	0	0	0	1	2
Availability of warehouse space	1	1	0	1	0	3
Fluctuations in demand	1	1	1	1	1	5
Labor productivity	1	0	0	1	1	3
Quality of manufactured products	0	1	0	0	1	2

Source: compiled by the authors

In fact, tables 3.10 and 3.11 define the criteria of importance for one or another production and logistics system. It should be noted that in scientific research there is no precise formal definition of the concept of the importance of criteria, therefore, as a rule, this task is solved by an informal method with the involvement of experts who proceed from their own understanding of the importance of individual indicators. As a result, we obtain criteria for evaluating the importance of indicators for both systems.

Table 3.12 – Criteria for evaluating the importance of indicators for pulling and pushing systems

Indicator	Degree of importance			
	pulling	coefficient	pushing	coefficient
Reliability of the supplier	5	0.33	2	0.07
Availability of warehouse space	1	0.07	3	0.27
Fluctuations in demand	2	0.13	5	0.33
Labor productivity	3	0.2	3	0.2
Quality of manufactured products	4	0.27	2	0.13

Thus, the decision-making hierarchy has the following form:

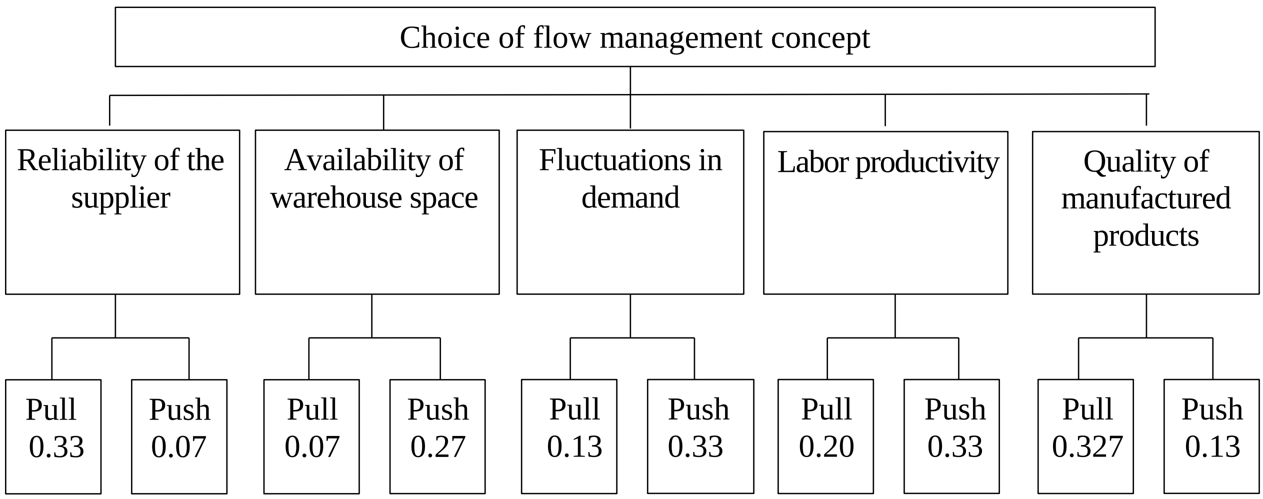


Fig. 3.4 Hierarchy of decision-making for choosing a logistics concept

Source: compiled by the authors

The evaluation of the two systems is based on the calculation of a combined weighting factor for each of them.

Tensile: 0.33N1 + 0.07 N2 + 0.13 N3 + 0.20 N4 + 0.27 N5 = x1.

Pushing: 0.07 N1 + 0.27 N2 + 0.33 N3 + 0.33 N4 + 0.13 N5 = x2.

Accordingly, the system with a greater combined weighting factor is optimal for this enterprise based on the available indicators.

Let's calculate the value of these indicators for the enterprise"Sphere-Auto"(table 3.13).

Table 3.13 – Values of indicators affecting decision-making when choosing a production and logistics concept for an enterprise "Sphere-Auto"

Indicator	Indicator	Partialcoefficient	Integratedcoefficient
Reliability of the supplier	Coefficient of the volume of supplies	$n_1 = \frac{4754520}{5150380} = 0.92$	N1=0.56
	Coefficient of timeliness of deliveries	$n_2 = \frac{10\ постач/міс}{13\ постач/міс} = 0.77$	
	Quality factor of supplied materials	$n_3 = \frac{148\ т/міс}{151\ т/міс} = 0.98$	
	Supplier remoteness factor	$n_4 = 90\% \ \geq \ 100\ км = 0.1$	
Security warehouse areas	Coefficient of security of the area of maintenance of work-in-progress	$n_5 = \frac{120220}{124610} = 0.96$	N2=0.64
	Coefficient of provision of the area of storage of finished products	$n_6 = \frac{90000}{94500} = 0.95$	

	Coefficient of securitystorage area of raw materials	$n_7 = \frac{148000}{145500} = 1{,}02$	
Fluctuations in demand	The coefficient of deviation of actual sales from the planned ones	$n_8 = \frac{5360800 \text{ грн/міс}}{6742000 \text{ грн/міс}} = 0.8$	N3=0.8
Productivity labor	Performance level	$n_9 = \frac{12100}{9900} = 1{,}22$	N4=1.22
Quality of manufactured products	Coefficient of quality of manufactured products	$n_{10} = \frac{1450 \text{ т/міс}}{1490 \text{ т/міс}} = 0.97$	N5=0.97

Source: compiled by the authors

Based on the obtained integrated coefficients, we will calculate the combined weighting coefficient for the pulling and pushing systems of the enterprise"Sphere-Auto"

Traction: 0.33 * 0.56 + 0.07 * 0.64 + 0.13 * 0.8 + 0.2 * 1.22 + 0.27 * 0.97 = 0.84.

Pushing: 0.07 * 0.56 + 0.27 * 0.64 + 0.33 * 0.8 + 0.33 * 1.22 + 0.13 * 0.97 = 0.99.

The obtained results showed that today it is more profitable at the enterprise to use a push production and logistics system. And in view of the importance and values of the criteria, for the transition to the pulling system of enterprise flow management"Sphere-Auto"first of all, it is necessary to pay attention to working with suppliers, improving relations with them or finding new suppliers.

If it is impossible to implement a pulling strategy (as in the object of the study), the enterprise needs to conduct an analysis of the factors that prevent the change of the production and logistics system. When identifying a problem and finding a solution, an important aspect is to eliminate the underlying causes of non-compliance. At the same time, all obstacles to building a compelling concept can be divided into surmountable and insurmountable. Irresistible causes, as a rule, lie in the external environment of the company, which it cannot influence, first of all, it is the nature of consumption or the specifics of production technology, its dependence on chemical or biological processes. In this case, the company is forced to find other tools to achieve the set goal. Obstacles to overcome, as a rule, are the characteristics of the company's internal environment. For example, the peculiarities of interaction between shops, departments, with suppliers, customers, etc. When working with them, you should develop a plan for solving the problem and the stages of its implementation. After eliminating the root causes, you can return to assessing the possibility of building a traction system.

3.3 Application of reliability assessment models in transport and logistics systems

Despite the diversity of these factors, common to all models is the desire to reduce stocks and maintain the optimal economic size of the order. The model of the optimal economic order size EOQ, better known as the Wilson model (formula), ensures the minimum amount of total costs and makes it possible to minimize the costs of storing inventory and ordering them. The calculation mechanism of the EOQ model is based on the minimization of total operational and logistics costs for the purchase and maintenance of stocks at the enterprise. These expenses are divided into two groups in advance:

1) the amount of costs for placing orders: the amount of costs for importing goods, costs for transportation and receiving goods. The costs of placing orders for the supply of production stocks are defined as the ratio of the volume of production consumption of raw materials and materials for the period to the average volume of one batch of supplies, multiplied by the average cost of placing one order;

2) the sum of the costs of keeping goods in the warehouse, defined as the product of half the average volume of one batch of raw material supply and the average storage cost of a unit of production stock.

The EOQ model allows you to optimize the proportions between these two groups of costs so that their total sum is minimal. For this, Wilson's formula is used, which has the form:

$$EOQ = \sqrt{\frac{2 \times D \times C}{3^{1}_{xp}}} \tag{3.25}$$

where: EOQ – the optimal average volume of the supply batch of raw materials, materials, etc.;

D – the volume of production consumption of raw materials and materials for the period;

C – the average cost of placing one order for the supply of raw materials and materials;

3^{1}_{xp} – the average cost of storage of a unit of production stock for the period.

With the increase in the average size of one shipment of goods, the operating costs of placing an order decrease and the operating costs of keeping stocks in the company's warehouse increase (and vice versa).

Therefore, the main task is to reconcile the costs of storing a large amount of inventory with the costs of placing the same number of orders. Accordingly, the optimal order size is a certain amount of stock, at which the total amount of costs for storage and ordering stock will be minimal. This level is determined by the so-called order point (Order Point), which determines the required quantity of ordered goods and is equal to the expected demand for the period of order fulfillment increased by the insurance stock.

Order Point=Daily Demand*Order Fulfillment Time+

+Insurance margin (3.26)

The disadvantage of this model is a rather rigid system of input prerequisites, in particular, the following assumptions are made: the demand for products is known, uniform and unchanged; product shortage is not allowed; goods are received instantly. These assumptions are not so critical for practice, and they can be bypassed if desired, without developing special modifications for this.

But in addition to them, the classic model has another significant drawback, which is related to the fact that the number of variables taken into account in it is too small and does not meet modern business requirements. However, this shortcoming was also eliminated by repeatedly modifying the EOQ model by various authors, with the aim of taking into account many additional factors caused by market development. And corporations with large supply chains and high variable costs use this algorithm in their computer software to determine the optimal economic order size.

Moreover, there are already some modifications of EOQ-models that allow to take into account the factors of carrying capacity/cargo capacity of vehicles and discounts for the organization of deliveries depending on the size of the container when calculating the parameters of the economic size of the order.

Therefore, in addition to the characteristics defined in the basic model of the optimal economic size of the EOQ order, transportation indicators, namely: the cost price and productivity of transportation, have a significant impact on the process of order formation and delivery.

The cost is related to the route and number of rides. It shows the effectiveness of using different models of rolling stock. The rolling stock in which this value is minimal is economically efficient and better. The full cost of road transport includes transportation costs St, which are taken into account by motor transport companies, forwarding services Se, loading and unloading works Snr and the road component Sa:

$$SP = St + Se + Snr + Sa \tag{3.27}$$

The cost of transportation consists of expenses related to the movement of the car and its idle time at the loading/unloading points. You can write that:

$$S_{\text{Т}} = \frac{\sum \text{С}_{\text{вит 1 їзд}}}{P_{\text{їзд}}(W_{\text{їзд}})}, \tag{3.28}$$

where: $\sum \text{С}_{\text{вит 1 їзд}}$ – amount of expenses for driving;

Ride (Wiezd) – volume of transportation or performed transport work per ride.

The total cost of driving consists of variable and fixed costs.

$$\sum \text{С}_{\text{вит 1 їзд}} = \sum C_{\text{змін}} + \sum C_{noc}. \tag{3.29}$$

$C_{\text{змін}}$ and C_{noc} depend on the carrying capacity of the car. These dependencies are linear and have the form:

$$C_{\text{змін}} = a_{\text{змін}} + b_{\text{змін}} \times q \times \gamma_{\text{СТ}}; \tag{3.30}$$

$$C_{noc} = a_{noc} + b_{noc} \times q \times \gamma_{\text{СТ}}. \tag{3.31}$$

where: $a_{\text{змін}}$ and $b_{\text{змін}}$ are constant coefficients (parameters) of dependence $C_{\text{змін}}$ =f(qγст);

a_{noc} *and* b_{noc} – constant coefficients (parameters) of dependence C_{noc} =f(qγст);

q – vehicle carrying capacity, t;

$\gamma_{\text{СТ}}$ – the static coefficient of utilization of the carrying capacity of the vehicle.

Productivity, on the other hand, includes the technical parameters of the route and is represented by such indicators as the average loading/unloading time, the carrying capacity of motor vehicles, etc. It is calculated according to the formula:

$$\text{p} = \frac{q_a \times y_c \times \beta \times V_{TA}}{L_{CA} + \beta \times V_{TA} \times t_{\text{н/р}}} \tag{3.32}$$

where: q_a – vehicle carrying capacity, t;

y_c – coefficient of statistical carrying capacity;

β – mileage utilization factor (<= 1);

V_{TA} – technical speed of the car, km/h;

L_{CA} – planned transportation distance, km;

$t_{н/р}$ – loading/unloading time of the car, hours

Accordingly, if the type of product, its volume and the carrying capacity of the vehicle are known, it is possible to calculate the average speed – Vsr and the loading/unloading time - $t_{н/р}$. Based on this data, the delivery time (T) of one order can be estimated

$$T = L/V_{cp}.+t_{н/р} \qquad (3.33)$$

Based on the delivery time, we receive the amount of the transport tariff in UAH. per hour. It should be noted that when transporting over long distances, the transport component becomes particularly important, as it can significantly exceed other components of the total costs of the supply chain (in some cases, up to 50% of the product's cost price). Therefore, if the average cost of placing one order C for the supply of raw materials, materials can be represented as the sum of the average operating costs for placing an order C and the average logistics costs for transportation St, as a group of costs that are an integral part of any order, then the optimal size lot (EOQ model) can be found by the formula:

$$EOQ = \sqrt{\frac{2D(С_0+C_т)}{З^1_{хр}}} \qquad (3.34)$$

The proposed approach allows you to connect the components of inventory management efficiency models in supply chains, in particular the EOQ model, with the productivity of the transport process and, as a result, to include in them the parameters of transportation of a technical nature:

$$С_т = 2y \times (\frac{L}{V_{cp}} + t_{н/p}) \times g = \frac{kygL}{V_{cp}} + kygt_{н/р} \qquad (3.35)$$

where: y – mileage utilization rate;

k – the number of trips per route;

g – tariff, $/hour

The $С_т$ indicator includes the product of transport work and the transport tariff, which allows us to move to the economic and value expression of the result.

Transport work, in turn, is represented by such indicators as the average loading/unloading time and the carrying capacity of motor vehicles. Thus, the formula for calculating transportation costs (C_T) includes essential parameters of transportation of a technical nature, which must be taken into account when planning the supply chain and determining the optimal size of the order. Then, when substituting formula 11 into formula 10, we get:

$$EOQ = \sqrt{\frac{2D(C_0 + \frac{kygL}{V_{cp}} + kegt_{н/p}}{З^1_{xp}}} \tag{3.36}$$

The resulting formula allows you to link transport costs with other types of costs, and in turn, the components of transport costs are reflected in the EOQ model.

At the same time, the modern market environment, along with the optimization of costs, places more and more demands on the participants of commodity-money relations related to the speed of customer service and increasing the efficiency and productivity of transport activities.

One of the main characteristics of any logistics system is the timeliness of deliveries, that is, the time parameter. The most common causes of delays in the practice of modern logistics enterprises include:

1) violation of the planned time for carrying out transportation - shifts the work to other areas, which, in turn, can lead to arrival at the unloading point (transshipment, customs control, port, etc.) during non-working hours;

2) intentional violation of delivery terms by the carrier (example for hourly payment);

3) lack of a mobile navigation system;

4) road accident, violation of the speed limit, etc.

Each of the identified reasons can be determined both objectively and subjectively, and depends on many factors. However, due to the fact that the modern market puts forward increased requirements for the fulfillment of all terms of the contract, in particular, the terms of delivery of goods, when building supply chains, it is appropriate to use the concept of just-in-time (JIT), which is based on the synchronization of volumes and quality of supplies in accordance with operational needs of production. It is based on the decentralized principle of material flow management, when instructions to start production come directly from the company's warehouse or sales system, and the key elements are integrated information processing, segmentation of production and deliveries, synchronized with production. Accordingly, having an accurate calculation of the duration of transportation is one of the basic ideas of the JIT concept, especially when it comes to supply chains and transportation related to them.

According to the specified strategy, the time calculation for finding the total duration of the transportation flight (taking into account the relevant operations: time of movement, accumulation, loading-unloading, etc.) is carried out according to the formula:

$$T_0 = \sum_{r=1}^{N} \sum_{i=1}^{A} t_{r,i} + \sum_{r=1}^{N} \sum_{j=1}^{B} \tau_{r,j} + \sum_{r=1}^{N} \sum_{k=1}^{C} \theta_{r,k} + \sum_{r=1}^{N} \sum_{l=1}^{D} \phi_{r,l} + \sum_{m=1}^{E} \psi_m + \sum_{n=1}^{F} \eta_n \quad (3.37)$$

where t,i + 1 – the travel time between the i-th and (i + 1)-th points;

where: τ_i – the time of processing customs documents at the jth point (within the country and at border crossings);

θ_r – time of loading, unloading and storage at the kth point;

θ_k A, B, C – the number of vehicle traffic sections and loading/unloading points, respectively;

φ_i – a random component reflecting an increase in flight time for repair and preventive works;

ψ_m – a random component reflecting restrictions related to the crew's work schedule and rest;

η_n – a random component that reflects prohibitions on the movement of vehicles along the route (weekends, accidents, malfunctions, etc.);

D, E, F – the number of cases of downtime of the vehicle, taking into account the specified reasons, respectively;

r – an index reflecting a certain type of transport for multimodal transport (for example, when using road, rail and sea transport on the route at the same time N = 3).

Given that in the specified model one of the components ψ_m is related to the peculiarities of the work and rest regime of drivers (accumulation of the driver's working time during driving, which is a limitation for each day of the vehicle's movement during the flight), in our opinion, it should be limited by inequality

$$\sum t_{i,\mathrm{i}+1} \leq \mathrm{T}_{\text{уп}} \tag{3.38}$$

where: Tup is the normalized duration of driving a vehicle per day ($\mathrm{T}_{\text{уп}}$ = 9 hours).

In addition, we have to introduce a restriction related to the duration of Tweed's daily rest

$$\sum t_{i,\mathrm{i}+1} + \tau_{\mathrm{i}} + \theta_{\text{к}} + \phi_l + \eta_n \leq 24 - \mathrm{T}_{\text{від}} \tag{3.39}$$

In which the statistical parameters of the cycle – time and root mean square deviation - are determined by the formulas:

$$\bar{\mathrm{T}} = \sum_{i=1}^{N} \bar{T}_i, \tag{3.40}$$

$$\sigma_T = \sqrt{\sum_{i=1}^{N} \sigma_i^2 + 2\sum_{i \leq j} r_{ij}\sigma_i\sigma_j}, \tag{3.41}$$

where: T – the average value of the operation time of the i-th cycle;

σ_T – average squared deviation of the operation time of the i-th cycle;

r_{ij} – the correlation coefficient between the i-th and j-th operations of the cycle.

The refinements proposed by us for the model for evaluating the performance of transport operations according to JIT allow obtaining more accurate data on the total total time of transportation; delivery probabilities or delivery time with a given probability. And the model built in this way allows you to take into account all the variety of factors affecting the duration of transportation, which enables managers at the planning stage to assess all threats and risks that their designed supply chain may potentially face. The advanced model for determining the time of transportation for several types of transport allows you to carry out an analytical assessment of the key indicator of transportation, namely the duration of logistics cycles, and make a competent decision based on calculations. Which, in turn, will allow obtaining probabilistic estimates of transport operations in accordance with JIT concepts. This model differs from the existing empirical approach in that it allows the decomposition of the transportation process into separate components and describes them as independent elements using statistical parameters.

Approbation of the model for the comprehensive assessment of the efficiency of transportation in supply chains requires the availability of a comprehensive information database. The result of the calculations and the convenience of their implementation depend on how correct and complete the initial data will be. The issue of forming a reference and information base for comprehensive assessment of target indicators can be conditionally divided into groups.

The first group of questions is related to existing corporate reporting (management accounting, accounting, annual profit and loss statement) and the possibility of using this data for evaluation. The second group is a logistics service report on key functions at the enterprise: monthly / quarterly / annual reports on supply, production and sales. The third group of issues refers to the collection and obtaining of lower-level information on all transport functions and related operations: data of technological maps, operating diagrams of rolling stock, reports on the operation of loaders at the terminal, etc.

In addition to taking into account the technological map, we conducted daily monitoring of the operation of the warehouse area and based on this data, a daily work schedule was formed, which is a source of data for the formation of an information and reference base.

CONCLUSIONS

The monograph provides a theoretical generalization of methods and techniques aimed at increasing the reliability of the supply chain, proposes a hierarchical classification of models for evaluating and ensuring the reliability of operations in supply chains, which can serve as a conceptual basis for the modeling process, and develops a set of economic and mathematical models for evaluating the reliability of the supply chain in conditions uncertainties aimed at improving the efficiency of the supply chain.

The conducted research provides grounds for drawing the following theoretical and scientific-practical conclusions:

1. Despite the rapid development of logistics and supply chain management around the world, many theoretical and practical problems in the reliability of supply chains remain unsolved. These include the problems of developing a classification of assessment methods and models and ensuring the reliability of operations in supply chains, as well as the problems of developing planning models for individual business processes in supply chains under conditions of uncertainty and risk.

Studying the work of supply chains, scientists single out four main groups of factors that affect the reliability of the supply chain: the factor of production equipment, the factor of flows, the factor of process integration, and the factor of information exchange. The presence of certain factors requires the application of certain approaches to their reduction or elimination in practical activities. Among them, the following are the most widespread: the process approach and the SCOR model developed on its basis; creation of dynamic supply chains; evaluation of the quality of logistics service based on the "perfect order" indicator. Regarding methods of assessing the reliability of the supply chain, it is also fashionable to divide them into groups. The first group is based on the ability of the supply chain to quickly and efficiently recover from a disruption to a normal or even desirable state. In the second group, reliability refers to the ability of the supply chain to adapt to and recover from catastrophic events. In the third, reliability is described as the ability of the supply chain to be prepared for potential failures, to be able to reduce the impact of these events as soon as they occur, and to minimize the time required to restore to a standard state.

2. From the point of view of reliability, the supply chain can be considered efficient only when all participants of the supply chain are in normal condition and have minimal (allowable) costs for the promotion of goods to the consumer, and the structure of the supply chain is perfect. Therefore, the reliability of the supply chain is completely determined by the reliability of the companies involved in the promotion of the product and the structure of the supply chain system. And the failure of any of them will not improve the reliability of the supply chain system.

A perfect or near-perfect supply chain structure can significantly increase its ability to prepare for, respond to, and recover from disruptions. Thus, a centralized, extended supply chain with a simpler structure and fewer levels can demonstrate greater stability, maintaining a steady state even in the face of disruptions.In contrast, a decentralized supply chain with multiple sources of supply can be more resilient because a failure at one node is easier to isolate and contain. In addition, the structure of the supply chain can affect how long it takes to restore it to a standard level. A well-structured network can ensure the rapid transfer of information and resources, mitigating the effects of failures. Which in turn makes it easier to find alternative suppliers or transport routes quickly, reducing downtime and costs associated with supply chain disruptions

3. The analysis of ensuring the reliability of individual business processes has been a concern of scientists for a long time, as evidenced by the large number of developed models. At the same time, it is noteworthy that the largest number

of reliability models and methods relate to the "planning" business process, while certain aspects of this problem (in particular, those related to production, distribution and backflow management) are not sufficiently developed.

Comprehensive reliability assessment and assurance models, i.e. models covering several related business processes, are insufficiently developed. The reason is that complex models are much more complex in the mathematical aspect. The search for return flow management models based on the "reliability" criterion yielded virtually no results. "The return flow optimization model based on the "costs to restore the consumer value of the product" criterion only partially meets the specified requirements, because it is based on an economic criterion, not reliability. Planning models of individual business processes are also constantly developing and supplemented with new developments. The largest number of scientific works is devoted to the problems of calendar production planning, routing of vehicles, selection of suppliers and optimization of the size of the delivery lot.

4. All methods for modeling the improvement of supply chain reliability should be considered from the point of view of three approaches:

1) Technical, based on the theory of reliability of technical systems, in which circuit elements are connected in series, in parallel and combined with various types of active or passive redundancy. The main objects here are: reliability criteria of technical systems of various purposes; reliability analysis methods in the process of designing and operating technical systems; methods of synthesis of technical systems; ways of ensuring and improving the reliability of equipment; scientific methods of operating equipment that ensure its high reliability and others.To calculate reliability, it is necessary to design the structure of the supply chain system in the form of a structural diagram of the reliability of its elements.

2) Economic, which is built on the "ideal" order model or the "supply and demand" model. It provides an assessment of the reliability of supply chains based

on the optimization of procurement costs, logistics, breach of contractual obligations (penalties, fines, etc.) or indicators of profit and profitability of business processes in supply chains. In this sense, the reliability of the supply chain is its ability to ensure the value of the economic indicators of its functioning within the limits that guarantee the system timely achievement of its goals with minimal expenditure of material, labor and other resources or with the maximum possible economic effect in the planned time interval.

3) Safe, which takes into account the dangers that may arise in the supply chain and is based on the theory of risk management. It provides possible options for actions in case of unforeseen circumstances, based on the basic concepts of "just in time", quick response, etc. The security criterion in supply chains is usually analyzed in terms of interactions between system participants and the external environment, the status and assessment of hazard and risk accounting.

5. All multi-level models of supply chain reliability can be divided into four categories according to the nature of the origin of input data and the purpose of the study:

1) economic models (demand and supply, determination of the ideal order quantity, optimization of logistics service);

2) deterministic analytical models, in which the variables are known and specified (given requirements of reliability, functional reliability, structural reliability, just in time);

3) stochastic analytical models, in which at least one of the variables is unknown and it is assumed that it will follow a certain probability distribution (a dynamic model of the task of optimizing the lot size and choosing suppliers taking into account the area of warehouse space, budget constraints and a stochastic model of the same task under demand conditions , which changes);

4) simulation (imitation) models (event-based modeling, process-based modeling, agent-based modeling).

6. The optimal supply plan for a multi-channel supply network is the result of solving a mathematical programming problem, where the reliability of the network channel is included in the optimization plan. This approach makes it possible to solve the problem not only of ensuring the necessary uninterrupted supply with minimal costs, but also to choose a chain of channels with the highest reliability. This model is one of the directions in the development of supply planning optimization models, taking into account the reliability (failure) of the execution of strategic plans and the definition of supply chains with high reliability. However, given that a supply network can consist of channels with different characteristics, a structural reliability network model will typically include channels consisting of individual suppliers and supply chains or even entire sub-networks with a relatively complex (fractal) structure.

7. The work considers an example of calculating the reliability of supplies, which shows that, firstly, the point values of the supply reliability coefficient K_g and values of supply reliability in the supply of P do not give a complete picture of supply reliability, it is necessary to study the dynamics of these indicators. Second, it is necessary to select a theoretical distribution for the failure rate λ(t), since the exponential distribution, which is widely used for modeling the reliability of non-renewable systems, is not well suited for modeling the reliability of recoverable systems. Thirdly, the reliability function of the type under the normal distribution is inadequate to the classical understanding of reliability, that is, it is not the probability of the supplier's failure-free operation during the specified time t. Thus, it is necessary to continue research in this direction.

8.To make a decision on increasing the reliability of the supply chain, the research used the method of analyzing the hierarchy of the MAI, which allowed to substantiate the choice of the best of the alternative strategies. The conducted analysis showed that the performance indicators of the enterprise at this moment in time most fully meet the requirements of the pushing production and logistics flow management system, and at the same time provided an opportunity to identify areas that need to be worked on for further transition to the principles of the pulling concept. The identified problems at the enterprise are important factors in the construction of production and logistics systems based on the principles of extraction. Therefore, they can be used as criteria that influence the decision to choose a production and logistics concept.

9. The refinements proposed in the work for the evaluation model of the performance of transport operations according to JIT allow obtaining more accurate data on the total total time of transportation; delivery probabilities or delivery time with a given probability. And the built model allows you to take into account all the variety of factors that affect the duration of transportation, which allows managers at the planning stage to assess all threats and risks that their projected supply chain may potentially face. The advanced model for determining the time of transportation for several types of transport allows you to carry out an analytical assessment of the key indicator of transportation, namely the duration of logistics cycles, and make a competent decision based on calculations. Which, in turn, will allow obtaining probabilistic estimates of transport operations in accordance with JIT concepts. This model differs from the existing empirical approach in that it allows the decomposition of the transportation process into separate components and describes them as independent elements using statistical parameters.

REFERENCES

1. Барабанов І.В., Бутенко О. П. Оптимізація рівня запасів на підприємстві з використанням формули Вілсона. Вісник економіки транспорту і промисловості. 2011. № 36. 118-121.

2. Ivan Nazarenko, Iryna Bernyk, Oleg Dedov, Ivan Rogovskii, Mykola Ruchynskyi, Ivan Pereginets, Liudmyla Titova. Research of technical systems of processes of mixing materials. Dynamic processes in technological technical systems. Kharkiv: PC Technology Center. P. 57-76. https://doi.org/10.15587/978-617-7319-49-7.ch4.

3. Гірна О. Ланцюг поставок: оцінювання надійності постачальника. Економіка та суспільство, 2022. (41). https://doi.org/10.32782/2524-0072/2022-41-39.

4. Загурський О.М. Підходи щодо вимірювання показників оцінки логістичного сервісу в ланцюгах постачань. Збірник «Вісник економіки транспорту і промисловості». №78-79. 2022. 70-77.

5. Загурський О.М. Управління ланцюгом постачань : підручник. Київ : ФОП Ямчинський О.В., 2023. 333.

6. Загурський О., Загурська С. Моделювання маршрутів транспортно-логістичної системи постачань швидкопсувних харчових продуктів. International Science Journal of Engineering & Agriculture, 2022. 1(3), 216-228. URL. https://isg-journal.com/isjea/article/view/30

7. Abbasi M., Varga, L. Steering supply chains from a complex systems perspective, European Journal of Management Studies, 2022, Vol. 27 No. 1, 5-38. https://doi.org/10.1108/EJMS-04-2021-0030

8. Abolghasemi M., Beh E., Tarr G., Gerlach R. Demand forecasting in supply chain: The impact of demand volatility in the presence of promotion, Computers & Industrial Engineering, Volume 142, 2020, 106380.

9. Abolghasemi M., Hurley J., Eshragh A., Fahimnia B. Demand forecasting in the presence of systematic events: Cases in capturing sales promotions, International Journal of Production Economics, Volume 230, 2020, 107892.

10. Ab Talib M.S., Abdul Hamid A.B., Thoo A.C. Critical success factors of supply chain management: a literature survey and Pareto analysis, EuroMed Journal of Business, 2015, Vol. 10 No. 2, 234-263. https://doi.org/10.1108/EMJB-09-2014-0028.

11. Ahmed H.F., Hosseinian-Far A., Khandan R., Sarwar D., E-Fatima K. Knowledge Sharing in the Supply Chain Networks: A Perspective of Supply Chain Complexity Drivers. Logistics 2022, 6, 66. https://doi.org/10.3390/logistics6030066.

12. Ahmed S., Akbar M., Ullah R. et al. ARCUN: analytical approach towards reliability with cooperation for underwater WSNs, Procedia Computer Science, 2015, vol. 52, 576-583.

13. Akkermans H., van Wassenhove L.N. Supply chain tsunamis: Research on low-probability, high-impact disruptions Journal of Supply Chain Management, 54 (1) (2018), 64-76.

14. Alonso-Jiménez J. A., Aranda-Corral, Joaquín Borrego-Díaz G. A., Fernández-Lebrón M. M., Hidalgo-Doblado M. J. A logic-algebraic tool for reasoning with Knowledge-Based Systems, Journal of Logical and Algebraic Methods in Programming, Volume 101, 2018, 88-109.

15. Alruqi M., Baumers M., Branson D.T., Girma S. The Challenge of Deploying Failure Modes and Effects Analysis in Complex System Applications–Quantification and Analysis. Sustainability 2022, 14, 1397. https://doi.org/10.3390/su14031397.

16. AL-Shboul M.A., An investigation of transportation logistics strategy on manufacturing supply chain responsiveness in developing countries: the mediating role of delivery reliability and delivery speed, Heliyon, Volume 8, Issue 11, 2022, e11283.

17. Amirian S., Amiri M., Taghavifard M.T. The Emergence of a Sustainable and Reliable Supply Chain Paradigm in Supply Chain Network Design, Complexity, vol. 2022, Article ID 9415465, 29. https://doi.org/10.1155/2022/9415465.

18. Amirian S., Amiri M., TaghaviFard M. T. The convergence between sustainability and reliability in the design of supply chain: a systematic literature review', Journal of Engineering in Industrial Research, 2023. 4(1), 1-8. doi: 10.22034/jeires.2023.1.1.1.

19. Anderson J.D., Mitchell J.L., Maples J.G. Invited Review: Lessons from the COVID-19 Pandemic for Food Supply Chains. Appl. Anim. Sci. 2021, 37, 738-747.

20. Arntzen B.C., Brown G. G. Harrison T. P., . Trafton L. L Global Supply Chain Management at Digital Equipment Corporation. Interfaces 1995. 25(1):69-93.

21. Asha A.A., Dulal M., Ahashan Habib Dr. The influence of sustainable supply chain management, technology orientation, and organizational culture on the delivery product quality-customer satisfaction nexus, Cleaner Logistics and Supply Chain, Volume 7, 2023, 100107.

22. Atabaki M. S., Mohammadi M., Naderi B. New robust optimization models for closed-loop supply chain of durable products: Towards a circular economy, Computers & Industrial Engineering, Volume 146, 2020, 106520, URL. https://doi.org/10.1016/j.cie.2020.106520

23. Aydin R., Badurdeen F. Sustainable product line design considering a multi-lifecycle approach, Resources, Conservation and Recycling, Volume 149, 2019, 727-737.

24. Ayan B., Güner E., Son-Turan S. Blockchain Technology and Sustainability in Supply Chains and a Closer Look at Different Industries: A Mixed Method Approach. Logistics 2022, 6, 85. https://doi.org/10.3390/logistics6040085

25. Ballou R.H. Business Logistics/Supply Chain Management: Planning, Organizing and Controlling the Supply chain. 5th Edition, Pearson/Prentice Hall Inc., New Jersey, 2004, 789.

26. BAROMETER. What Are the 10 Supply Chain Risks for 2023. URL. https://emag.directindustry.com/2023/01/27/barometer-what-are-the-10-supply-chain-risks-for-2023/

27. Basu D., Lee M. A combined sustainability-reliability approach in geotechnical engineering. In Risk, Reliability and Sustainable Remediation in the Field of Civil and Environmental Engineering. 2022. 379-413.

28. Beamon B.M, Supply chain design and analysis: Models and methods, International Journal of Production Economics, Volume 55, Issue 3, 1998, 281-294.

29. Behzadi G., O'Sullivan M.J., Olsen T.L. On metrics for supply chain resilience European Journal of Operational Research, 287 (1) 2020, 145-158.

30. Belhadi A., Kamble S., Jabbour C.J.C., Gunasekaran A., Ndubisi N.O., Venkatesh M. Manufacturing and service supply chain resilience to the COVID-19 outbreak: Lessons learned from the automobile and airline industries Technological Forecasting and Social Change, 163, 2021, Article 120447, URL. 10.1016/j.techfore.2020.120447

31. Ben Hassen T., El Bilali H. Impacts of the Russia-Ukraine War on Global Food Security: Towards More Sustainable and Resilient Food Systems? Foods 2022, 11, 2301. https://doi.org/10.3390/foods11152301.

32. Benedito E., Martínez-Costa C., Rubio S. Introducing Risk Considerations into the Supply Chain Network Design. Processes 2020, 8, 743. https://doi.org/10.3390/pr8060743.

33. Bosona T., Gebresenbet G. The Role of Blockchain Technology in Promoting Traceability Systems in Agri-Food Production and Supply Chains. *Sensors* 2023, *23,* 5342. https://doi.org/10.3390/s23115342.

34. Bodenheimer M., Leidenberger J. COVID-19 as a window of opportunity for sustainability transitions? Narratives and communication strategies beyond the pandemic. Sustain. Sci. Pract. Policy. 2020. 16, 61-66.

35. Bø E., Hovi I.B., Pinchasik D. R. COVID-19 disruptions and Norwegian food and pharmaceutical supply chains: Insights into supply chain risk management, resilience, and reliability, Sustainable Futures, Volume 5, 2023, 100102.

36. Bracke S., Inoue M., Ulutas B., Yamada T. CDMF-RELSUS Concept: Reliable and Sustainable Products–influences on Design, Manufacturing, Layout Integration and Use Phase, Procedia CIRP, Volume 15, 2014, 8-13.

37. Bradley R, Jawahir IS, Badurdeen F, Rouch K (2018) A total life cycle cost model (TLCCM) for the circular economy and its application to post-recovery resource allocation. Resour Conserv Recycl 135:141-149.

38. Brandenburg M., Warasthe R., Seuring S. Impact pathways: improving supply chain sustainability by due diligence acts? Insights from a German case, International Journal of Operations & Production Management, 2023, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/IJOPM-03-2023-0200.

39. Brown C. The End of Reliability. Journal of Water Resources Planning and Management, 2010, 136, 143-145.

40. Brown B. M., Kirby V. G., Pryce J. D. A Numerical Method for the Determination of the Titchmarsh-Weyl m-Coefficient Proceedings: Mathematical and Physical Sciences Vol. 435, No. 1895 (Dec. 9, 1991), 535-549.

41. Bueno-Solano A., edillo-Campos M. G., Velarde Cantú J. M. Reliability of the supply chain: method of self-assessment as a first step to

building resilient systems, International Journal of Combinatorial Optimization Problems and Informatics, 2016, vol. 7, no. 1, 3-9.

42. Butcher J.C. Numerical methods for ordinary differential equations in the 20th century, Journal of Computational and Applied Mathematics, Volume 125, Issues 1-2, 2000, 1-29.

43. Cajal-Grossi J., Del Prete D., Macchiavello R., Supply chain disruptions and sourcing strategies, International Journal of Industrial Organization, Volume 90, 2023, 103004.

44. Caniato F., Moretto A., Caridi, M. Dynamic capabilities for fashion-luxury supply chain innovation. International Journal of Retail and Distribution Management, 2013. 41(11/12), 940-960.

45. Cannella S. Order-Up-To policies in Information Exchange supply chains, Applied Mathematical Modelling, Volume 38, Issue 23, 2014, 5553-5561

46. Carkovs J., Matvejevs A., Matvejevs A., Kubzdela A.Stochastic modeling for transport logistics, Procedia Computer Science, Volume 149, 2019, 457-462.

47. Carvalho H., Naghshineh B., Govindan K., Cruz-Machado V. The resilience of on-time delivery to capacity and material shortages: An empirical investigation in the automotive supply chain, Computers & Industrial Engineering, Volume 171, 2022, 108375.

48. Castaneda J., Ghorbani E., Ammouriova M., Panadero J., Juan A.A. Optimizing Transport Logistics under Uncertainty with Simheuristics: Concepts, Review and Trends. Logistics 2022, 6, 42. https:// doi.org/10.3390/logistics6030042.

49. Castillo-Villar K.K., Smith N. R., Simonton J. L. A model for supply chain design considering the cost of quality, Applied Mathematical Modelling, Volume 36, Issue 12, 2012, 5920-5935.

50. Chang W.-S., Lin Y.-T. The effect of lead-time on supply chain resilience performance, Asia Pacific Management Review, Volume 24, Issue 4, 2019, 298-309.

51. Charles V., Emrouznejad A. Gherman T. A critical analysis of the integration of blockchain and artificial intelligence for supply chain. Ann Oper Res 327, 7–47. 2023. https://doi.org/10.1007/s10479-023-05169-w.

52. Cheaitou A., Cheaytou R. A two-stage capacity reservation supply contract with risky supplier and forecast updating, International Journal of Production Economics, Volume 209, 2019, 42-60.

53. Chen L., Dong T., Peng J., Ralescu D. Uncertainty Analysis and Optimization Modeling with Application to Supply Chain Management: A Systematic Review. Mathematics 2023, 11, 2530. https://doi.org/10.3390/math11112530.

54. Chen X., Xi Z., Jing P. A unified framework for evaluating supply chain reliability and resilience IEEE Transactions on Reliability, 66 (4), 2017, 1144-1156.

55. Cheng Y., Elsayed E.A., Huang Z. Systems resilience assessments: A review, framework and metrics. International Journal of Production Research, 1-28, 2021, URL. 10.1080/00207543.2021.1971789

56. Chen L, Dui H, Zhang C. A resilience measure for supply chain systems considering the interruption with the cyber-physical systems, Reliability Engineering & System Safety, Volume 199, 2020, 106869.

57. Cheng L., Rao C., Chen L. Multidimensional knapsack problem based on uncertain measure. Scientia Iranica Trans. E Ind. Eng. 2017, 24, 2527-2539.

58. Chirawat W., Tarathorn K, Vichai R. Inventory Lot-Sizing Problem with Supplier Selection under Storage Space and Budget Constraints // IJCSI International Journal of Computer Science Issues, Vol. 8, Issue 2, March 2011. 250-255.

59. Chowdhury P, Paul SK, Kaisar S, Moktadir MA. COVID-19 pandemic related supply chain studies: A systematic review. Transp Res E Logist Transp Rev. 2021 Apr; 148:102271. doi: 10.1016/j.tre.2021.102271. Epub 2021 Feb 13. PMID: 33613082; PMCID: PMC7881707.

60. Christy D. P., Grout J. R. Safeguarding supply chain relationships, International Journal of Production Economics, Volume 36, Issue 3, 1994, 233-242.

61. Coelho L. C., Cordeau J-F., Laporte G. Heuristics for dynamic and stochastic inventory-routing, Computers & Operations Research, Volume 52, Part A, 2014, 55-67.

62. Cohen, M.A., Lee, H.L. Resource Deployment Analysis of Global Manufacturing and Distribution Networks. Journal of Manufacturing and Operations Management, 1989. 2, 81-104.

63. Cohen, M.A., Moon, S. Impact of production scale economics, manufacturing complexity, and transportation costs on supply chain facility networks, Journal of Manufacturing and Operations Management, 1990. Vol. 3, 269-292.

64. Corrales-Estrada A.M., Gómez-Santos L.L., Bernal-Torres C.A., Rodriguez-López J.E. Sustainability and Resilience Organizational Capabilities to Enhance Business Continuity Management: A Literature Review. Sustainability 2021, 13, 8196. https://doi.org/10.3390/su13158196.

65. Cui L., Yue S., Nghiem X-H., Duan M. Exploring the risk and economic vulnerability of global energy supply chain interruption in the context of Russo-Ukrainian war, Resources Policy, Vol. 81, 2023, 103373.

66. da Costa J. P. Silva A. L., Barcelò D., Rocha-Santos T., Duarte A. Threats to sustainability in face of post-pandemic scenarios and the war in Ukraine, Science of The Total Environment, Volume 892, 2023, 164509.

67. Delipinar G., Kocaoglu B., Using SCOR Model to Gain Competitive Advantage: A Literature Review, Procedia - Social and Behavioral Sciences, Volume 229, 2016, 398-406.

68. Deng L., Xu W., Luo J. Optimal Loan Pricing for Agricultural Supply Chains from a Green Credit Perspective. Sustainability 2021, 13, 12365. https://doi.org/10.3390/su132212365.

69. Dethlefs C., Ostermeier M., Hübner A. Rapid fulfillment of online orders in omnichannel grocery retailing, EURO Journal on Transportation and Logistics, Volume 11, 2022, 100082.

70. Dixit S., Singh S., Dhir S., Dhir S. Antecedents of strategic thinking and its impact on competitive advantage, Journal of Indian Business Research, 2021, Vol. 13 No. 4, 437-458. https://doi.org/10.1108/JIBR-08-2020-0262.

71. Dolgui A., Ivanov D. Exploring supply chain structural dynamics: New disruptive technologies and disruption risks, International Journal of Production Economics, Volume 229, 2020, 107886.

72. Durach C.F., Wieland A., Machuca J.A.D. Antecedents and dimensions of supply chain robustness: a systematic literature review, International Journal of Physical Distribution & Logistics Management, 2015, Vol. 45 No. 1/2, 118-137. https://doi.org/10.1108/IJPDLM-05-2013-0133

73. Dutta P, Choi TM, Somani S, Butala R. Blockchain technology in supply chain operations: Applications, challenges and research opportunities. Transp Res E Logist Transp Rev. 2020 Oct;142:102067. doi: 10.1016/j.tre.2020.102067.

74. Eckstein D., Goellner M., Blome C., Henke M. The performance impact of supply chain agility and supply chain adaptability: The moderating effect of product complexity International Journal of Production Research, 2015, 53 (10), 3028-3046.

75. Emmens T., Amrit C., Abdi A., Ghosh M. The promises and perils of Automatic Identification System data, Expert Systems with Applications, Volume 178, 2021, 114975.

76. Emrouznejad A., Abbasi S., Sıcakyüz C., Supply chain risk management: A content analysis-based review of existing and emerging topics, Supply Chain Analytics, Volume 3, 2023, 100031.

77. Esmaeili-Najafabadi E., Nezhad M. S. F., Pourmohammadi H., Honarvar M., Vahdatzad M. A. A joint supplier selection and order allocation model with disruption risks in centralized supply chain, Computers & Industrial Engineering, Volume 127, 2019, 734-748.

78. Espino-Rodríguez T.F., Gebril Taha M. Absorptive Capacity and Supply Chain Integration and Their Impact on Hotel Service Performance. *Adm. Sci.* 2023, *13*, 247. https://doi.org/10.3390/admsci13120247.

79. Fang Y.-P., Zio E. An adaptive robust framework for the optimization of the resilience of interdependent infrastructures under natural hazards. European Journal of Operational Research, 276 (3), 2019, 1119-1136.

80. Fattahi M. Resilient procurement planning for supply chains: A case study for sourcing a critical mineral material, Resources Policy, Volume 74, 2021, 101093.

81. Feliciani T., Luo J., Ma L, Lucas P., Squazzoni F., Marušić A., Shankar K. A scoping review of simulation models of peer review. Scientometrics. 2019; 121(1): 555-594. doi: 10.1007/s11192-019-03205-w. Epub 2019 Aug 19. PMID: 31564758; PMCID: PMC6744516.

82. Feller I., Glasmeier A., Mark M. Issues and perspectives on evaluating manufacturing modernization programs. Research Policy, 1996, 25(2), 309-319.

83. Fischedick M., Schneidewind, U. The Corona crisis and climate protection-keeping long-term goals in mind. Sustainability Management Forum | NachhaltigkeitsManagement Forum. 2020. 28, 77-81.

84. Fishburn P. Utility Theory // Management Science. 1968. Vol. 14, No. 5. 335-378.

85. García-Reyes H., Avilés-González J., Avilés-Sacoto S. V. A Model to Become a Supply Chain 4.0 Based on a Digital Maturity Perspective, Procedia Computer Science, Volume 200, 2022, 1058-1067.

86. Ghazanfari M., Fatholla M. A comprehensive look at supply chain management, 1st edn. Iran Science and Technology University Publications, Tehran 2006.

87. Ghobakhloo M., Iranmanesh M., Mubarak M., Mubarik M., Rejeb A., Nilashi M. Identifying Industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values. Sustainable Production and Consumption. 2022. 33. 10.1016/j.spc.2022.08.003.

88. Ghodrati B. Reliability and Operating Environment Based Spare Parts Planning Luleå University of Technology Division of Operation and Maintenance Engineering, 2005. 21. URL. http://www.diva-portal.org/smash/get/diva2:990793/FULLTEXT01.pdf

89. Ghorbani M., Ramezanian R., Integration of carrier selection and supplier selection problem in humanitarian logistics, Computers & Industrial Engineering, Volume 144, 2020, 106473.

90. Grznár P., Gregor M., Krajčovič M., Mozol Š., Schickerle M., Vavrík V., Ďurica L., Marschall M., Bielik T. Modeling and Simulation of Processes in a Factory of the Future. *Appl. Sci.* 2020, *10,* 4503. https://doi.org/10.3390/app10134503

91. Golan M.S., Jernegan L.H., Linkov I. Trends and applications of resilience analytics in supply chain modeling: Systematic literature review in the context of the COVID-19 pandemic Environment Systems and Decisions, 40 (2020), 222-243.

92. Gowrisankaran G., Rysman M. Dynamics of Consumer Demand for New Durable Goods. Journal of Political Economy, vol. 120, no. 6, 2012, pp. 1173–219. JSTOR, https://doi.org/10.1086/669540.

93. Gunasekaran A. Ngai E.W.T. Build-to-order supply chain management: a literature review and framework for development, Journal of Operations Management, Volume 23, Issue 5, 2005, 423-45.

94. Gurtu A., Johny J. Supply Chain Risk Management: Literature Review. Risks 2021, 9, 16. https://doi.org/10.3390/risks9010016.

95. Habibi F., Chakrabortty R.K., A Abbasi A., Evaluating supply chain network resilience considering disruption propagation, Computers & Industrial Engineering, Volume 183, 2023, 109531.

96. Hahn G., Kuhn H. Value-based performance and risk management in supply chains: A robust optimization approach. International Journal of Production Economics. 2011. 139. 135-144. 10.1016/j.ijpe.2011.04.002.

97. Hagspiel S. Reliability with interdependent suppliers, European Journal of Operational Research, 2018, vol. 268, 1, 161-173.

98. Hagspiel S. Supply Chain Reliability and the Role of Individual Suppliers, EWI Working Paper, Institute of Energy Economics at the University of Cologne (EWI), Köln, 2016. 31.

99. Hajghasem M., Shojaie A.A. Optimal Routing in Supply Chain Aimed at Minimizing Vehicle Cost and Supply, Procedia Economics and Finance, Volume 36, 2016, 353-362.

100. Hammami R., Frein Y., Albana A. S. Delivery time quotation and pricing in two-stage supply chains: Centralized decision-making with global and local managerial approaches, European Journal of Operational Research, Volume 286, Issue 1, 2020, 164-177.

101. Han C., Jeon H., Oh J., Lee H. Dynamic Order Picking Method for Multi-UAV System in Intelligent Warehouse. *Remote Sens*. 2022, *14*, 6106. https://doi.org/10.3390/rs14236106.

102. Harrington E.C.Jr. The desirability Function. Industrial Quality Control, 1965. April. V. 21. № 10. 494-498.

103. He Y., Yin S. Cost analysis in global supply chains, Operations Research Letters, Volume 48, Issue 5, 2020, 658-665.

104. Holgado de Frutos E, Trapero JR, Ramos F. A literature review on operational decisions applied to collaborative supply chains. PLoS One. 2020 Mar 13;15(3):e0230152. doi: 10.1371/journal.pone.0230152.

105. Hosseini S., Barker K. Modeling infrastructure resilience using Bayesian networks: A case study of inland waterway ports, Computers & Industrial Engineering, Volume 93, 2016, 252-266.

106. Hosseini S., Ivanov D. A new resilience measure for supply networks with the ripple effect considerations: A Bayesian network approach Annals of Operations Research, 1–27, 2019,10.1007/s10479-019-03350-8.

107. Hosseini S., Ivanov D. Dolgui A. Review of quantitative methods for supply chain resilience analysis Transportation Research Part E: Logistics and Transportation Review, 125 (2019), 285-307.

108. Hou Y., Wang X., Wu Y.J., He P. How does the trust affect the topology of supply chain network and its resilience? An agent-based approach Transportation Research Part E: Logistics and Transportation Review, 116, 2018, 229-241.

109. Hübner A., Holzapfel A., Kuhn, H. Distribution systems in omni-channel retailing. 2016. Bus Res 9, 255-296. https://doi.org/10.1007/s40685-016-0034-7

110. Ibne H.N.U., Fazio S. A., Lawrence E. DR J.-M., Gonzalez S., Jaradat R., Alvarado M. S. Role of systems engineering attributes in enhancing supply chain resilience: Healthcare in context of COVID-19 pandemic, Heliyon, Volume 8, Issue 6, 2022, e09592.

111. Iranmanesh M., Maroufkhani P., Asadi S., Ghobakhloo M., Dwivedi Y. K., Tseng M. Effects of supply chain transparency, alignment, adaptability,

and agility on blockchain adoption in supply chain among SMEs, Computers & Industrial Engineering, Volume 176, 2023, 108931.

112. Ishii K, Takahashi K., Muramatsu R. Integrated production, inventory and distribution systems, International Journal of Production Research, 1988. 26:3, 473-482.

113. Islam S. S.M., Hoque A., Hamzah N. Single-supplier single-manufacturer multi-retailer consignment policy for retailers' generalized demand distributions, International Journal of Production Economics, Vol. 2017. 184, 2017, 157-167

114. Jagtap S., Trollman H., Trollman F., Garcia-Garcia G., Parra-López C., Duong L., Martindale W., Munekata P.E.S., Lorenzo J.M., Hdaifeh A. et al. The Russia-Ukraine Conflict: Its Implications for the Global Food Supply Chains. *Foods* 2022, *11*, 2098. https://doi.org/10.3390/foods11142098

115. Jamehshooran B.G., Shaharoun M., Awaluddin & Habibah H. Assessing supply chain performance through applying the SCOR model. 2015. 4. 1-11.

116. Jiang P., Wang Y., Liu C., Hu Y.-C., Xie J. Evaluating Critical Factors Influencing the Reliability of Emergency Logistics Systems Using Multiple-Attribute Decision Making. *Symmetry* **2020**, *12*, 1115. https://doi.org/10.3390/sym12071115

117. Kain R., Verma A. Logistics Management in Supply Chain – An Overview, Materials Today: Proceedings, Volume 5, Issue 2, Part 1, 2018, 3811-3816.

118. Kankam G., Kyeremeh E., Som G. N. K. Isaac Tetteh Charnor, Information quality and supply chain performance: The mediating role of information sharing, Supply Chain Analytics, Volume 2, 2023, 100005.

119. Karevan A., Tee K. F., Vasili M. A reliability-based and sustainability-informed maintenance optimization considering risk attitudes for

telecommunications equipment. International Journal of Quality & Reliability Management. ahead-of-print. 2020. 10.1108/IJQRM-04-2020-0114.

120. Kaur H., Singh S.P. Disaster resilient proactive and reactive procurement models for humanitarian supply chain Production Planning & Control, 33 (6–7) (2022), 576-589.

121. Kaur H., Singh S. P. Multi-stage hybrid model for supplier selection and order allocation considering disruption risks and disruptive technologies, International Journal of Production Economics, Volume 231, 2021, 107830.

122. Kendrick J. D., Saaty D. Use Analytic Hierarchy. Process For Project Selection. Six sigma forum magazine. 2007. 22-29. URL: http://engexecforum.com/ external%20files/Use%20Analytic%20Heirarch%20for%20Project%20Selection.p df

123. Knight L., Tate W., Carnovale S., Di Mauro C., Bals L., Caniato F., Gualandris J., Johnsen T., Matopoulos A., Meehan J., Miemczyk J.Future business and the role of purchasing and supply management: Opportunities for 'business-not-as-usual' PSM research, Journal of Purchasing and Supply Management, Volume 28, Issue 1, 2022, 100753.

124. Kochan C., Nowicki D. Supply chain resilience: a systematic literature review and typological framework. International Journal of Physical Distribution & Logistics Management. 2018. 48. 10.1108/IJPDLM-02-2017-0099.

125. Koons-Stapf A. Reliability & Maintainability Applications in Logistics & Supply Chain. 2015. 10.1109/RAMS.2015.7105108.

126. Kubon M., Kaczmar I., Findura P. Reliability of technical systems and the methodology for calculating MTBF using Flexsim computer simulation. E3S Web of Conferences. 2019. 132. 01012. 10.1051/e3sconf/201913201012.

127. Kumar D., Soni G., Kazancoglu Y., Rathore A.P.S. On the nature of supply chain reliability: models, solution approaches and agenda for future research, International Journal of Quality & Reliability Management, 2023, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/IJQRM-08-2022-0256

128. Kungwalsong K., Cheng C.-Y., Yuangyai C., Janjarassuk U. Two-Stage Stochastic Program for Supply Chain Network Design under Facility Disruptions. *Sustainability* 2021, *13*, 2596. https://doi.org/10.3390/su13052596.

129. Laari S., Lorentz H., Jonsson P., Lindau R. "Procurement's role in resolving demand–supply imbalances: an information processing theory erspective", International Journal of Operations & Production Management, 2023. Vol. 43 No. 13, 68-100. https://doi.org/10.1108/IJOPM-06-2022-0382

130. Law A., Kelton D. Simulation Modeling and Analysis. 2nd ed. New York ; Madrid etc. : McGraW-Hill 1991 759. O. Ozkan, S. Kilic, A Monte Carlo Simulation for Reliability Estimation of Logistics and Supply Chain Networks, IFAC-PapersOnLine, Volume 52, Issue 13, 2019, 2080-2085.

131. Lee H.L., Feitzinger E.: Product configuration and postponement for supply chain efficiency. In: Proceedings of the 1995 4th Industrial Engineering Research Conference, Nashville – USA. 1995. 43-48.

132. Lee I., Mangalaraj G. Big Data Analytics in Supply Chain Management: A Systematic Literature Review and Research Directions. Big Data Cogn. Comput. 2022, 6, 17. https://doi.org/10.3390/bdcc6010017.

133. Lee O-K., Sambamurthy V., Lim K.H., Wei K.K. How does IT ambidexterity impact organizational agility? Information Systems Research, 26 (2), 2015, 398-417.

134. Lei X., MacKenzie C. A. Assessing risk in different types of supply chains with a dynamic fault tree, Computers & Industrial Engineering, 2019, Volume, 137, 27. 106061.

135. Li D., Jiao J., Wang S, Zhou G. Supply Chain Resilience from the Maritime Transportation Perspective: A Bibliometric Analysis and Research Directions, Fundamental Research, 2023, https://doi.org/10.1016/j.fmre.2023.04.003.

136. Li L., Liu M., Shen W., Cheng G. An improved stochastic programming model for supply chain planning of MRO spare parts, Applied Mathematical Modelling, Volume 47, 2017, 189-207.

137. Li Y., Zobel C. W. Exploring supply chain network resilience in the presence of the ripple effect, International Journal of Production Economics, Volume 228, 2020, 107693.

138. Li Y., Zobel C. W., Seref O., Chatfield D. Network characteristics and supply chain resilience under conditions of risk propagation, International Journal of Production Economics, Volume 223, 2020, 107529.

139. Linton J. D., Boyson S., Aje J. The challenge of cyber supply chain security to research and practice – An introduction, Technovation, Volume 34, Issue 7, 2014, 339-341.

140. Liu L., Song W., Liu Y. Leveraging digital capabilities toward a circular economy: Reinforcing sustainable supply chain management with Industry 4.0 technologies, Computers & Industrial Engineering, Volume 178, 2023, 109113.

141. Lloyd D.K., Lipov M. Reliability: organization of investigations, methods, mathematical apparatus. Moscow : Sov. radio, 1964. 699.

142. Lohmer J., Ribeiro da Silva E., Lasch, R. Blockchain Technology in Operations & Supply Chain Management: A Content Analysis. Sustainability 2022, 14, 6192. https://doi.org/10.3390/su14106192.

143. Lopes de Sousa Jabbour A. B., Chiappetta Jabbour C. J., Hingley M., Vilalta-Perdomo E. L., Ramsden G., and Twigg, D. Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic: lessons and trends. Modern Supply Chain Res. 2020. Appl. 2, 117-123.

144. Lohner-Moeslang K. New challenges in the area of supply chain risk management: Unpredictable events and their effects, Journal of Applied Leadership and Management, ISSN 2194-9522, Hochschule Kempten -

University of Applied Sciences, Professional School of Business & Technology, Kempten, 2022, Vol. 10, Iss. 60-84. https://journal-alm.org/article/view/23357/

145. Lu Q., Meng F., Goh M. Choice of supply chain governance: Self-managing or outsourcing? International Journal of Production Economics, Volume 154, 2014, 32-38.

146. MacCarthy B., Ahmed W., Demirel G. Mapping the supply chain: Why, what and how? International Journal of Production Economics, Volume 250, 2022, 108688.

147. Margariti S.V., Dimakopoulos V.V., Tsoumanis, G. Modeling and Simulation Tools for Fog Computing–A Comprehensive Survey from a Cost Perspective. *Future Internet*, 2020, *12,* 89. https://doi.org/10.3390/fi12050089;

148. Majumdar A., Shaw M., Sinha S. K. COVID-19 debunks the myth of socially sustainable supply chain: a case of the clothing industry in South Asian countries. Sustain. Production Consumption 2020. 24, 150-155.

149. Martin-Breen J.M. Anderies Resilience: A Literature Review. Bellagio Initiative, Brighton:IDS. 2011, 64.

150. Martins V.W.B., Anholon R., Leal Filho W., Quelhas, O.L.G. Resilience in the supply chain management: understanding critical aspects and how digital technologies can contribute to Brazilian companies in the COVID-19 context. Modern Supply Chain Research and Applications, 2022, Vol. 4 No. 1, 2-18. https://doi.org/10.1108/MSCRA-05-2021-0005.

151. Matopoulos A., Barros A.C., van der Vorst J.G.A.J.(J) Resource-efficient supply chains: a research framework, literature review and research agenda, Supply Chain Management, 2015, Vol. 20 No. 2, pp. 218-236. https://doi.org/10.1108/SCM-03-2014-0090

152. Mazdeh M., Emadikhiav M., Parsa I., A heuristic to solve the dynamic lot sizing problem with supplier selection and quantity discounts, Computers & Industrial Engineering, Volume 85, 2015, 33-43

153. Mishra R., Singh R.K. A systematic literature review on supply chain resilience in SMEs: learnings from COVID-19 pandemic, International Journal of Quality & Reliability Management, 2023, Vol. 40 No. 5, 1172-1202. https://doi.org/10.1108/IJQRM-03-2022-0108.

154. Mohammadi M. Designing an integrated reliable model for stochastic lot-sizing and scheduling problem in hazardous materials supply chain under disruption and demand uncertainty, Journal of Cleaner Production, Volume 274, 2020, 122621.

155. Mohsen B. Impact of Artificial Intelligence on Supply Chain Management Performance. Journal of Service Science and Management, 2023, 16, 44-58. doi: 10.4236/jssm.2023.161004.

156. Muhammad M. Jajja S., Chatha K., Farooq S. Supply chain risk management and operational performance: The enabling role of supply chain integration, International Journal of Production Economics, Volume 227, 2020, 107667.

157. Ha N.T., Akbari M., Au B. Last mile delivery in logistics and supply chain management: a bibliometric analysis and future directions", Benchmarking: An International Journal, 2023, Vol. 30 No. 4, 1137-1170. https://doi.org/10.1108/BIJ-07-2021-0409

158. Nezhad F, Mohammad S. A Stochastic Dynamic Programming for Production Planning of Processes Industries. A Stochastic Dynamic Programming for Production Planning of Processes Industries. 2016. 27. 547-562.

159. Niamat U. I., Fazio S. A., Lawrence J., Gonzalez E., Jaradat R., Alvarado M. S., Role of systems engineering attributes in enhancing supply chain resilience: Healthcare in context of COVID-19 pandemic, Heliyon, Volume 8, Issue 6, 2022, e09592.

160. Nolan J.P. Modeling financial data with stable distributions. Department of Mathematics and Statistics, American University. 2005. 105-130.

161. Nosrati M., Khamseh A. Reliability optimization in a four-echelon green closed-loop supply chain network considering stochastic demand and carbon price, Uncertain Supply Chain Management, 2020, vol. 8, no. 3, 457-472.

162. Novak D.C., Wu Z., Dooley K.J. Whose resilience matters? Addressing issues of scale in supply chain resilience Journal of Business Logistics, 42(3), 2021, 323-335.

163. Ntabe E.N., LeBel L., Munson A.D., Santa-Eulalia L.A. A systematic literature review of the supply chain operations reference (SCOR) model application with special attention to environmental issues, International Journal of Production Economics, Volume 169, 2015, 310-332.

164. Omoruyi O., Mafini C. Supply Chain Management and Customer Satisfaction in Small to Medium Enterprises. Studia Universitatis Babe-Bolyai Oeconomica. 2016. 61. 10.1515/subboec-2016-0004.

165. Ozkan O., Kilic S. A Monte Carlo Simulation for Reliability Estimation of Logistics and Supply Chain Networks, IFAC-PapersOnLine, Volume 52, Issue 13, 2019, 2080-2085.

166. Parwani V., Hu G. Improving Manufacturing Supply Chain by Integrating SMED and Production Scheduling. *Logistics 2*021, *5*, 4. https://doi.org/10.3390/logistics5010004

167. Pastore E., Alfieri A., Zotteri G., Boylan J. E. The impact of demand parameter uncertainty on the bullwhip effect, European Journal of Operational Research, Volume 283, Issue 1, 2020, 94-107.

168. Peeters K., van Ooijen H. Hybrid make-to-stock and make-to-order systems: a taxonomic review, International Journal of Production Research, 2020, 58:15, 4659-4688, doi: 10.1080/00207543.2020.1778204.

169. Pettit T. J., Fikse J., Croxton K. L. Ensuring supply chain resilience: development of a conceptual framework. J. Business Logistics 2010, 31, 1-21.

170. Pereira V. J., Vieira S. F. A., Capucho P. H. P., Vera Suguihiro L. T., Tridapalli J. P. Cost management in the supply chain: An analysis of the costs of

different types of municipal procurement, Social Sciences & Humanities Open, Volume 5, Issue 1, 2022, 100260.

171. Powell W. B., Simao H. P., -Ayari B.B. Approximate dynamic programming in transportation and logistics: a unified framework, EURO Journal on Transportation and Logistics, Volume 1, Issue 3, 2012, 237-284.

172. Quezada F., Gicquel C, Kedad-Sidhoum S., Vu D. Q. A multi-stage stochastic integer programming approach for a multi-echelon lot-sizing problem with returns and lost sales, Computers & Operations Research, Volume 116, 2020, 104865.

173. Raghavendar K., Batra I., Malik A. A robust resource allocation model for optimizing data skew and consumption rate in cloud-based IoT environments, Decision Analytics Journal, Volume 7, 2023, 100200.

174. Raj A., Mukherjee A.A., de Sousa Jabbour A.B.L., Srivastava S.K. Supply chain management during and post-COVID-19 pandemic: Mitigation strategies and practical lessons learned. J Bus Res. 2022 Mar; 142:1125-1139. doi: 10.1016/j.jbusres.2022.01.037.

175. Raja Santhi A., Muthuswamy P. Influence of Blockchain Technology in Manufacturing Supply Chain and Logistics. Logistics 2022, 6, 15. https://doi.org/10.3390/logistics6010015.

176. Ramezankhani M.J., Ali Torabi S., Vahidi F. Supply chain performance measurement and evaluation: A mixed sustainability and resilience approach, Computers & Industrial Engineering, Volume 126, 2018, 531-548.

177. Ramos E., Dien S., Gonzales A., Chavez M., Hazen B. Supply chain cost research: a bibliometric mapping perspective, Benchmarking: An International Journal, 2021, Vol. 28 No. 3, 1083-1100. https://doi.org/10.1108/BIJ-02-2020-0079.

178. Reefke H., Sundaram D. Sustainable supply chain management: Decision models for transformation and maturity, Decision Support Systems, Volume 113, 2018, 56-72.

179. Rinaldi M., Murino T., Gebennini E, Morea D., Bottani E. A literature review on quantitative models for supply chain risk management: Can they be applied to pandemic disruptions? Computers & Industrial Engineering, Volume 170, 2022, 108329.

180. Rita P., Oliveira T., Farisa A. The impact of e-service quality and customer satisfaction on customer behavior in online shopping, Heliyon, Volume 5, Issue 10, 2019, e0269.

181. Rodriguez-Aguilar R., Marmolejo-Saucedo J.A. Structural Dynamics and disruption events in Supply Chains using Fat Tail Distributions, IFAC-PapersOnLine, Volume 52, Issue 13, 2019, 2686-2691.

182. Ruel S., El Baz J., Ivanov D. et al. Supply chain viability: conceptualization, measurement, and nomological validation. Ann Oper Res 2021. https://doi.org/10.1007/s10479-021-03974-9.

183. Saaty T. L. The Hierarchon: A Dictionary of Hierarchies. Pittsburgh, Pennsylvania : RWS Publications, 1996. 510.

184. Sadjadi S. J., Makui A., Dehghani E., Pourmohammad, M. Applying queuing approach for a stochastic location-inventory problem with two different mean inventory considerations, Applied Mathematical Modelling, Volume 40, Issue 1, 2016, 578-596.

185. Sahoo S., Kumar S., Sivarajah U., Lim W.M., Westland J.C., Kumar A. Blockchain for sustainable supply chain management: trends and ways forward. Electron Commer Res. 2022 May 27:1–56. doi: 10.1007/s10660-022-09569-1.

186. Saen R. F., Izadikhah, M.. A novel SCOR approach to assess the sustainability of supply chains. *Operations Management Research.*. 2022. https://doi.org/10.1007/s12063-022-00331-2

187. Sarkis J., Cohen M. J., Dewick P., Schröder P.. A brave new world: Lessons from the COVID-19 pandemic for transitioning to sustainable supply and production. Resourc. Conserv. Recycl. 2020. 159:104894.

188. Sawik T.A portfolio approach to supply chain disruption management International Journal of Production Research, 55 (7). 2017, 1970-1991.

189. Serhat Karakutuk S., Arslan Ornek M. A goal programming approach to lean production system implementation. Journal of the Operational Research Society 2023, 74:1, 403-416.

190. Setak M., Feizizadeh F., Tikani H., Shaker Ardakani E. A bi-level stochastic optimization model for reliable supply chain in competitive environments: Hybridizing exact method and genetic algorithm, Applied Mathematical Modelling, Volume 75, 2019, 310-332.

191. Seuring S., Müller M. From a literature review to a conceptual framework for sustainable supply chain management. J. Cleaner Production 2008. 16, 1699-1710.

192. Shapiro J. Modeling the Supply Chain] Cengage Learning, 2006. 618.

193. Shi S., Wang Y., Chen X., Zhang Q. Conceptualization of omnichannel customer experience and its impact on shopping intention: A mixed-method approach, International Journal of Information Management, Volume 50, 2020, 325-336.

194. Simchi-Levi D., Schmidt W., Wei Y. From superstorms to factory fires: Managing unpredictable supply chain disruptions Harvard Business Review, 92 (1–2) (2014), 96-101.

195. Skowron-Grabowska B, Wincewicz-Bosy M, Dymyt M, Sadowski A, Dymyt T, Wąsowska K. Healthcare Supply Chain Reliability: The Case of Medical Air Transport. Int J Environ Res Public Health. 2022 Apr 4;19(7):4336. doi: 10.3390/ijerph19074336. PMID: 35410017.

196. Son C. Supply Chain Risk Management: A Review of Thirteen Years of Research. American Journal of Industrial and Business Management, 2018, 8, 2294-2320. doi: 10.4236/ajibm.2018.812154.

197. Sorooshian S., Khademi Sharifabad S., Parsaee M., Afshari A.R. Toward a Modern Last-Mile Delivery: Consequences and Obstacles of Intelligent Technology. Appl. Syst. Innov. 2022, 5, 82. https://doi.org/10.3390/asi5040082.

198. Spieske A., Birkel, H. Improving supply chain resilience through industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic.Computers & Industrial Engineering, 158, 2021. 107452

199. Sukati I., Hamid A.B., Baharun R., Yusoff R.Md The Study of Supply Chain Management Strategy and Practices on Supply Chain Performance, Procedia - Social and Behavioral Sciences, Volume 40, 2012, 225-233.

200. Tadayonrad Y., Ndiaye A.B. A new key performance indicator model for demand forecasting in inventory management considering supply chain reliability and seasonality, Supply Chain Analytics, Volume 3, 2023, 100026.

201. Taghizadeh H., Hafezi E. The investigation of supply chain's reliability measure: a case study. J Ind Eng Int 8, 22 (2012). https://doi.org/10.1186/2251-712X-8-22

202. Tao L., Liu S., Xie N., Javed S. A. Optimal position of supply chain delivery window with risk-averse suppliers: A CVaR optimization approach, International Journal of Production Economics, Volume 232, 2021, 107989.

203. Tikwayo L.N., Mathaba T.N.D. Applications of Industry 4.0 Technologies in Warehouse Management: A Systematic Literature Review. Logistics 2023, 7, 24. https://doi.org/10.3390/ logistics7020024.

204. Timoumi A., Gangwar M., Mantrala M.K. Cross-channel effects of omnichannel retail marketing strategies: A review of extant data-driven research, Journal of Retailing, Volume 98, Issue 1, 2022, 133-151.

205. Tiwari S., Sharma P., Choi T.-M., Lim A., Blockchain and third-party logistics for global supply chain operations: Stakeholders' perspectives and decision roadmap, Transportation Research Part E: Logistics and Transportation Review, Volume 170, 2023, 103012.

206. Towill D.R. Supply Chain Dynamics. International Journal of Computer Integrated Manufacturing, 1991. 4, 197-208.

207. Vaez P., Sabouhi F., Saeed Jabalameli M. Sustainability in a lot-sizing and scheduling problem with delivery time window and sequence-dependent setup cost consideration, Sustainable Cities and Society, Volume 51, 2019, 101718.

208. Vanany I., Zailani S., Pujawan N. Supply Chain Risk Management: Literature Review and Future Research. IJISSCM. 2009. 2. 16-33.

209. van Delft Ch., Vial J.-Ph. A practical implementation of stochastic programming: an application to the evaluation of option contracts in supply chains, Automatica, Volume 40, Issue 5, 2004, 743-756.

210. van Engelenhoven T., Kassahun A., Tekinerdogan B. Systematic Analysis of the Supply Chain Operations Reference Model for Supporting Circular Economy. Circ.Econ.Sust. 2023. 3, 811-834 https://doi.org/10.1007/s43615-022-00221-6.

211. Vega de la Cruz, Leudis O., Pérez-Pravia, Milagros C. Gestión integrada de riesgos de la seguridad de las cadenas de suministros con enfoque al servicio al cliente. Ingeniería y competitividad, 2022. 24(2), e202111197.

212. Vegter D., van Hillegersberg J., Olthaar M. Supply chains in circular business models: processes and performance objectives, Resources, Conservation and Recycling, Volume 162, 2020, 105046.

213. Venegas B. B., Ventura J. A. A two-stage supply chain coordination mechanism considering price sensitive demand and quantity discounts, European Journal of Operational Research, Volume 264, Issue 2, 2018, 524-533.

214. Verma M., Plaisier C., van Wagenberg C.P.A., Achterbosch T. A Systems Approach to Food Loss and Solutions: Understanding Practices, Causes, and Indicators. *Sustainability* 2019, *11*, 579. https://doi.org/10.3390/su11030579.

215. Vilko J., Hallikas J. Risk assessment in multimodal supply chains, International Journal of Production Economics, Volume 140, Issue 2, 2012, 586-595.

216. Velenturf A., Purnell P. Principles for a sustainable circular economy, Sustainable Production and Consumption, Volume 27, 2021,1437-1457.

217. Vojtov V., Kutiya O., Berezhnaja N., Karnaukh M., Bilyaeva, O. Modeling of reliability of logistic systems of urban freight transportation taking into account street congestion. Eastern-European Journal of Enterprise Technologies, 2019, 4(3 (100), 15–21. https://doi.org/10.15587/1729-4061.

218. von Berlepsch D., Lemke, F., Gorton, M. The Importance of Corporate Reputation for Sustainable Supply Chains: A Systematic Literature Review, Bibliometric Mapping, and Research Agenda. J Bus Ethics . 2022. https://doi.org/10.1007/s10551-022-05268-x,

219. Wang G. Dou W., Zhu W., Zhou N. The effects of firm capabilities on external collaboration and performance: The moderating role of market turbulence Journal of Business Research, 68 (9), 2015, 1928-1936.

220. Wang B., Zhang H., Yuan M., Guo Z., Liang Y. Sustainable refined products supply chain: a reliability assessment for demand - side management in primary distribution processes, Energy Science & Engineering, 2020, vol. 8, no. 4, 1029-1049.

221. Welsh C. The Russia-Ukraine War and Global Food Security: A Seven-Week Assessment, and the Way Forward for Policymakers. CSIS. 2022. Available online: https://www.csis.org/analysis/russia-ukraine-war-and-global-food-security-seven-week-assessment-and
wayforward#:~:text=Food%20price%20increases%
20due%20to,percent%20of%20their%20wheat%20imports

222. Wilson R.H. A scientific routine for stock control. Harv. Bus. Rev. 1934, 13, 116-129.

223. Wiengarten F., Humphreys P., Gimenez C., McIvor R., Risk, risk management practices, and the success of supply chain integration, International Journal of Production Economics, Volume 171, Part 3, 2016, 361-370.

224. Woarawichai C., Kullpattaranirun T., Rungreunganun V. Inventory Lot-Sizing Problem with Supplier Selection under Storage Space and Budget Constraints. IJCSI International Journal of Computer Science Issues, 2011. Vol. 8, Issue 2, 250-255.

225. Yaghin R. G. Enhancing supply chain production-marketing planning with geometric multivariate demand function (a case study of textile industry), Computers & Industrial Engineering, Volume 140, 2020, 106220.

226. Yang J., Xie H., Yu G., Liu M., Achieving a just–in–time supply chain: The role of supply chain intelligence, International Journal of Production Economics, Volume 231, 2021, 107878.

227. Yaghin R. G. Enhancing supply chain production-marketing planning with geometric multivariate demand function (a case study of textile industry), Computers & Industrial Engineering, Volume 140, 2020, 106220.

228. Zadeh L. Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic. Fuzzy sets and systems, 1997. Vol. 90, No. 2, 111-127.

229. Zagurskiy O. M. Modeling of supply processes for perishable foodstuffs. Machinery & Energetics. Journal of Rural Production Research. Kyiv. Ukraine. 2021, Vol. 12, No 3, 53-61.

230. Zagurskiy O. Systematic and evolutionary approach to market research. Economic Annals-XXI, 2014, 11-12, 8-11.

231. Zagurskyi O., Ohiienko M., Pokusa T., Zagurska S., Pokusa F., Titova L., Rogovskii I. Study of efficiency of transport processes of supply chains management under uncertainty. Monograph. Opole: The Academy of Management and Administration in Opole, 2020; 162.

232. Zagurskiy O., Pivtorak M., Bondariev S., Demin O., Kolosok I. Methods of reliability management in supply chain. Proceedings of 22st International Scientific Conference Engineering for Rural Development 24-26.05.2023 Jelgava, LATVIA. 76-84.

233. Zagurskyi O., Pokusa T., Duczmal M., Ohiienko M., Zagurska S., Titova L., Rogovskii I. Ohiienko A. Supply chain logistics service system: methods and models of its optimization. Monograph. Opole: The Academy of Management and Administration in Opole, 2022; 192.

234. Zagurskiy O., Titova L. «Problems and Prospects of Blockchain Technology Usage in Supply Chains» Journal of Automation and Information Sciences, 2019. Volume 11. 63-74. URL. http://www.dl.begellhouse.com/ru/journals/2b6239406278e43e,5c564c68149f41e1,0564ac535ef99ad2.html

235. Zagurskiy O., Savchenko L., Makhmudov I., Matsiuk V. Assessment of socio-ecological efficiency of transport and logistics activity. Proceedings of 21st International Scientific Conference Engineering for Rural Development 25-27.05.2022 Jelgava, LATVIA. 543-550.

236. Zagursky O. M., Slipukha T.I. Comparative analysis of production - logistics systems that based on push and pull strategies. Machinery & Energetics. Journal of Rural Production Research. Kyiv. Ukraine. 2019, Vol. 10, No 3, 69-78.

237. Zagurskiy O., Zahurska S., Titova L., Rogovskii I. Of blockchain-technology usage in supply chains / Socio-economic development of the regions in conditions of transformation. Monograph. Opole: The Academy of Management and Administration in Opole, 2020. 13-22.

238. Zhang M., Chen J., Chang S-H., An adaptive simulation analysis of reliability model for the system of supply chain based on partial differential equations, Alexandria Engineering Journal, Volume 59, Issue 4, 2020, 2401-2407.

239. Zeng Z., Chen Y., Zio E., Kang R. A compositional method to model dependent failure behavior based on PoF models, Chinese Journal of Aeronautics, Volume 30, Issue 5, 2017, 1729-1739.

240. Zeng Z., Kang R., Chen Y., Using PoF models to predict system reliability considering failure collaboration, Chinese Journal of Aeronautics, Volume 29, Issue 5, 2016, 1294-1301.

AKADEMIA
NAUK
STOSOWANYCH
WYŻSZA SZKOŁA ZARZĄDZANIA
I ADMINISTRACJI W OPOLU

НУБіП
1898
TRADERE PROGREDI PROSPICERE

ISBN 978-83-66567-64-1
978 83 66567 64 1