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# ASSESSING THE LOGISTIC SYSTEM MATURITY LEVEL IN INTEGRATED SUPPLY CHAINS UNDER LOGISTIC 4.0 PARADIGM

The fourth industrial revolution and digital technologies have transformed the logistics industry, leading to the emergence of Logistics 4.0 paradigm with interconnected systems, robots, big data analytics, and data-driven decision-making, which is crucial for enhancing supply chain resilience, sustainability, and customer-centricity. In this regard, the need to continuous investment in logistics system maturity assessment and development has been identified. This research article analyzes existing maturity assessment models for business systems, summarizes these models, and discusses their potential transformation under the influence of digitalization. The importance of evaluating maturity levels is highlighted through existing research but emphasizes that merely identifying maturity levels is insufficient, as improvements are necessary following the evaluation. Moreover, existing models that evaluate maturity levels need to improve accounting for industry-specific contexts and provide specific quality indicators rather than focusing on the description of maturity levels. The article aims to develop the theoretical and methodological foundations for the logistics system maturity in integrated supply chain evaluation and provide a framework for organizations to identify areas for improvement with the Logistics 4.0 paradigm. The article's hypotheses suggest that improving such factors as digital transformation, supply chain integration, organizational culture, strategic alignment, human capital, workforce development, partnerships, and collaborations can enhance the maturity level of logistic systems, leading to improved supply chain performance, but some barriers and challenges need to be overcome with the fourth industrial revolution achievements. The mutual influence of the described hypotheses highlights three key areas for evaluating logistics maturity: the level of formalization within the integration process, the maturity of individual participants, and the utilization of opportunities provided by the fourth industrial revolution. The interpretation of integrated logistic system maturity level has been given. The article provides a comprehensive interpretation of the maturity level of integrated logistics systems, which are proposed to identify based on the developed hierarchical model of fuzzy inference. Under the fuzzy model, indicators for assessing different aspects of logistic maturity have been offered, and response scenarios to maturity assessment results have been developed.

**Keywords:** logistics; logistics integration; maturity level; supply chains; fuzzy inference; directions of logistics optimization

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# ОЦІНЮВАННЯ ЛОГІСТИЧНОЇ ЗРІЛОСТІ ІНТЕГРОВАНИХ ЛАНЦЮГІВ ПОСТАЧАННЯ ЗА ПАРАДИГМОЮ ЛОГІСТИКИ 4.0

Четверта промислова революція та цифрові технології змінили галузь логістики, що призвело до появи парадигми логістики 4.0 із взаємопов'язаними системами, роботами, аналітикою великих даних та прийняттям рішень на основі даних, що має вирішальне значення для підвищення стійкості ланцюга постачання та забезпечення підвищення рівня клієнтоорієнтованості. У зв'язку із цим актуалізувалась потреба постійного інвестування в оцінювання та забезпечення зростання зрілості логістичної системи. У цій дослідницькій статті аналізуються існуючі моделі оцінки зрілості бізнес-систем, узагальнюються ці моделі та обговорюється їх потенційна трансформація під впливом цифровізації. Важливість оцінювання рівнів зрілості підкріплюється наявними дослідженнями, але підкреслюється, що простого визначення рівнів зрілості недостатньо, оскільки після оцінювання необхідні вдосконалення. Крім того, існуючі моделі оцінювання рівня зрілості повинні бути покращені врахуванням галузевих контекстів через кількісні показники, а не лише через орієнтацію на опис рівнів зрілості. Метою статті є розвиток теоретико-методичних засад оцінювання зрілості логістичних процесів інтегрованих ланцюгів постачань і визначення областей їх вдосконалення за допомогою парадигми логістики 4.0. Гіпотези статті припускають, що вдосконалення таких факторів, як цифрова трансформація, інтеграція ланцюга поставок, організаційна культура, стратегічне узгодження, людський капітал, розвиток робочої сили, партнерства та співпраця, може підвищити рівень зрілості логістичних систем, що призведе до покращення продуктивності ланцюга поставок. Взаємний вплив описаних гіпотез виділяє три ключові сфери для оцінки зрілості логістики: рівень формалізації інтеграційного процесу, зрілість окремих учасників логістичної взаємодії та використання наданих четвертою промисловою революцією можливостей. Подано інтерпретацію рівня зрілості інтегрованих логістичних систем, які запропоновано ідентифікувати на основі розробленої ієрархічної моделі нечіткого логічного висновку. Розроблено сценарії реагування логістичних систем на отримані результати оцінювання.

**Ключові слова:** логістика; логістична інтеграція; рівень зрілості; ланцюги постачань; нечіткий логічний висновок; напрями логістизації

**The urgency of the research.** The fourth industrial revolution and digital technologies have widely spread and have brought a paradigm shift in the logistics industry, rendering some traditional logistics methods inadequate and necessitating the development of powerful new tools. The Logistics 4.0 paradigm, characterized by interconnected systems, robots and cyber-system involvement, big data analytics, supply chain integration, data-driven decision-making, etc., has emerged as a reasonable response to the new digital challenges. Enterprises and their associations could face such challenges only through increasing logistic system maturity levels that could have different ways of understanding but are crucial in all their meanings. Increasing maturity levels provides invaluable insights for enhancing supply chain resilience, sustainability, and customer-centricity.

**Target setting.** As the global logistics industry evolves rapidly under the digital influence, pursuing knowledge in logistics system maturity assessment is a critical field of inquiry that requires an ongoing investment of intellectual capital and resources. Organizations must have the tools and frameworks to gauge their logistics maturity levels accurately. Such assessments can enable them to identify potential areas for improvement, compete effectively, craft strategic initiatives to fortify their logistical prowess and thrive in a volatile business environment.

**Actual scientific researches and issues analysis.** The maturity level of systems and business processes has been considered by many researchers and is mentioned in various reference models. A list of existing maturity assessment models and directions for their possible transformation under the digitalization influence (these directions are defined by the authors of this article) has presented in Table 1. Based on the presented systematization of information, the maturity of business processes can be defined as the degree to which the process meets the requirements of certainty, manageability, measurability, replicability, and performance. In turn, the logistic maturity level refers to the maturity of an organization's logistics processes and capabilities, including managing inventory, transportation, etc.

Table 1 – System maturity level frameworks and directions of its possible development under the digitalization influence

| Framework | Essence of model | Model Levels | Digitalization impact |
|---|---|---|---|
| CMMI (Capability Maturity Model Integration) [4] | A framework for process improvement. It is designed to help organizations enhance their product and service development, delivery, and maintenance capabilities. | 1. Initial<br>2. Managed<br>3. Defined<br>4. Managed<br>5. Optimizing | It should be expanded by process optimization through such digital technologies as AI, IoT, and data analytics, which can facilitate continuous improvement and innovation across processes within the organization. |
| Logistics Maturity Model (LMM) [1; 12] | A comprehensive model was developed to evaluate logistics performance and capabilities, focusing on logistics processes' efficiency and integration. | 1. Ad hoc<br>2. Fragmented<br>3. Integrated<br>4. Optimized<br>5. Advanced | Given model should also be improved through end-to-end visibility, real-time data-driven decision-making, and increased automation like blockchain and robotics preces (RPA) |
| SCOR (Supply Chain Operations Reference) Model [2; 8] | It is a management tool that provides a standard framework for evaluating, improving, and communicating supply chain performance across industries | 1. Reactive<br>2. Anticipatory<br>3. Collaborative<br>4. Orchestrating<br>5. Cognitive | The fourth industrial revolution can help the SCOR model's core elements (Plan, Source, Make, Deliver, Return) optimization through better demand forecasting and collaboration among supply chain partners |
| Gartner's Five-Stage Maturity Model for Manufacturing Excellence [7; 10] | The maturity model offers a strategic framework to achieve manufacturing excellence by aligning people, processes, and technology. | 1. Chaotic<br>2. Structured<br>3. Integrated<br>4. Orchestrated<br>5. Continuous | For the manufacturing capabilities improvement it is possible to use digitalization for transition from lower maturity stages to higher stages of the model, enabling excellence |
| Industry 4.0 Maturity Model [3; 11] | A model that evaluates the digital maturity of manufacturing companies based on technological, organizational, and strategic dimensions. | 1. Computerize<br>2. Connectivity<br>3. Visibility<br>4. Transparency<br>5. Adaptability | Digital transformation can accelerate an organization's progress across the maturity stages of this model, from Computerization to Visibility, fostering a higher degree of automation and resilience |

The information presented in Table 1 provides an overview of the most prevalent models for assessing the maturity of systems and processes. Additionally, Table 1 encompasses the authors' perspective on the influence of informatization and digitalization on these models. The table includes not only references to the models themselves but also to the implementation of evaluation processes in an academic context. For example, by usage of SCOR [8] I. Bukhori, K. Widodo, and D. Ismoyowati [2] investigate the performance of a poultry supply chain in a Yogyakarta-based slaughtering house. Expanding SCOR by Analytical Hierarchy Process methods helps identify areas for improvement of logistic operations for company efficiency. Such an example proves the importance of assessing the level of maturity. The Same with Five-Stage Manufacturing Excellence Maturity Model developed by Gartner's Company [7] and widely revealed by researchers such as C. Siedler [10]. This model consists of seven dimensions, such as goal, data, skill sets, organizational structure, applications, analytics techniques, and supporting technology, each of which evaluates the extent of digitalization within various phases of a product's lifecycle. But anyway, it is not enough only to distinguish the maturity levels due to the necessity to make some improvement after evaluation.

**Uninvestigated parts of general matters defining.** As it shown in author's expanding in Table 1, the fourth industrial revolution and the influence of digital technologies can lead to significant improvements across various maturity models by driving enhanced process optimization, increased automation, data-driven decision-making, and better integration and collaboration, ultimately fostering organizational agility and resilience. However, Table 1 focuses more on business processes rather than logistics. Nevertheless, Several researchers have studied the maturity models of logistics systems operating within the logistics' 4.0 framework. For example, J. Oleskow-Szlapka and A. Stachowiak [9] offered the estimation model specifically designed to scrutinize the degree of progress achieved in logistics processes within the context of the fourth industrial revolution. Even though the given in [9] model is based on six dimensions (process, organization, technology, human resources, management, and performance) and helps to identify the enterprise's strengths and weaknesses in logistics processes, several areas for mentioned model improvement could be determined. Such areas consider the influences of different contexts and industries on the logistic maturity level and provide specific strategies for improving logistics processes rather than just identifying strengths and weaknesses. The same areas of improvement are relevant to K. Werner-Lewandowska's and M. Kosacka-Olejnik's [12] article, similar to those described in Table 1 Logistics Maturity Model (LMM) but for the service company was presented. In [12], proposals emphasize the breakdown of the LLM in areas of planning, procurement, storage, inventory management, distribution, and reverse logistics, each of which should be further expanded to take into account digital transformation. So, the models mentioned above delineate areas that require consideration of maturity levels, but they solely entail defining features of said levels. Hence, it is essential to incorporate quantitative characteristics, which is also impossible to implement with Industry 4.0 impact fully.

**The research objective.** The article aims to develop the theoretical and methodological foundations for the logistics system maturity in integrated supply chain evaluation and provide a framework for organizations to identify areas for improvement with the Logistics 4.0 paradigm. Achieving the article's goal involves solving the following tasks: identifying and analyzing the key factors influencing integrated supply chain logistics systems' maturity level; developing a comprehensive maturity assessment framework for evaluating the logistics system maturity level with various dimensions; providing actionable recommendations for an integrated supply chain' to use in own advantage opportunities from the Logistics 4.0 paradigm and digital transformation.

**The statement of basic materials.** Implementing the research objective could be based on fuzzy logic approach described by V. Gajovic [6] and A. Dorokhov [5] in their articles. The advantages of using fuzzy logic include: its ability to handle imprecise and uncertain data; flexibility in decision-making; its potential to model complex systems. The fuzzy logic approach is suggested to rely on multiple this article authors' hypotheses to ascertain the degree of maturity within the logistics system, particularly in integrated supply chains. The interaction between the proposed hypotheses (are defined by the set {H}) is shown in Fig. 1. The presented in Fig. 1 dependencies expand the idea that individual enterprises' integration increases the competitiveness of integrated supply chains. However, it is essential to note that competitiveness can only be enhanced through the growth of logistics maturity. The first integration stage may lead to a decline in logistics maturity due to the emergence of new procedures. To increase logistics maturity, utilizing the opportunities provided by the fourth industrial revolution is essential. The logistics maturity of an integrated supply chain depends on the maturity of its participants. Moreover, the existence of formalization within the integration process affects the level of logistics maturity. Participants in an integrated supply chain can enhance logistics maturity by attracting logistics practices from other participants. This approach can lead to the mutual development of logistics practices, thus contributing to the overall logistics maturity of the integrated supply chain. Although integration does not necessarily have to be formal, the level of logistics maturity depends on the existence of such formalization. Thus, the mutual influence of the described hypotheses and conditions allows for identifying three crucial areas for evaluating logistics maturity in an integrated supply chain, which are presented at the bottom of Fig. 1.

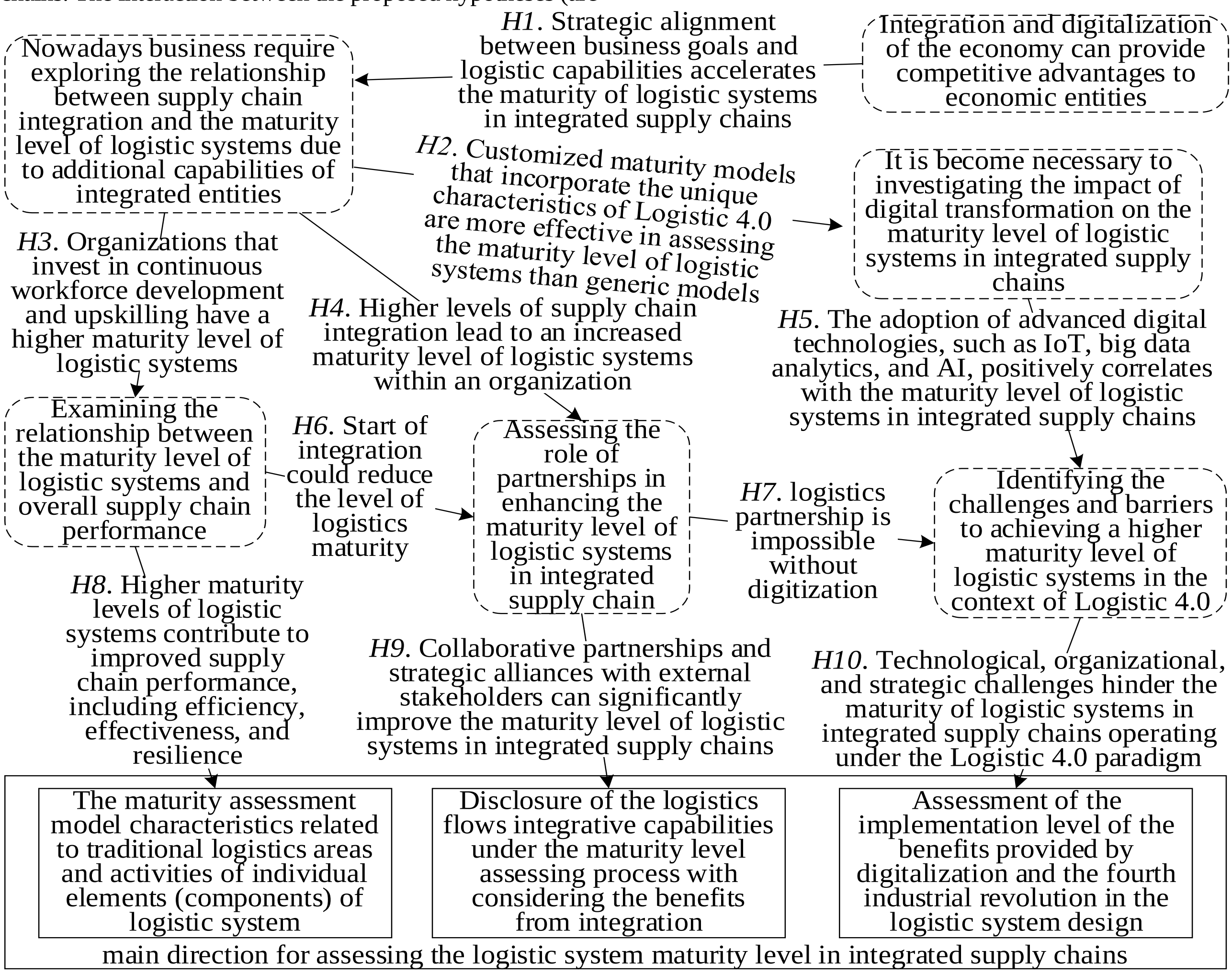
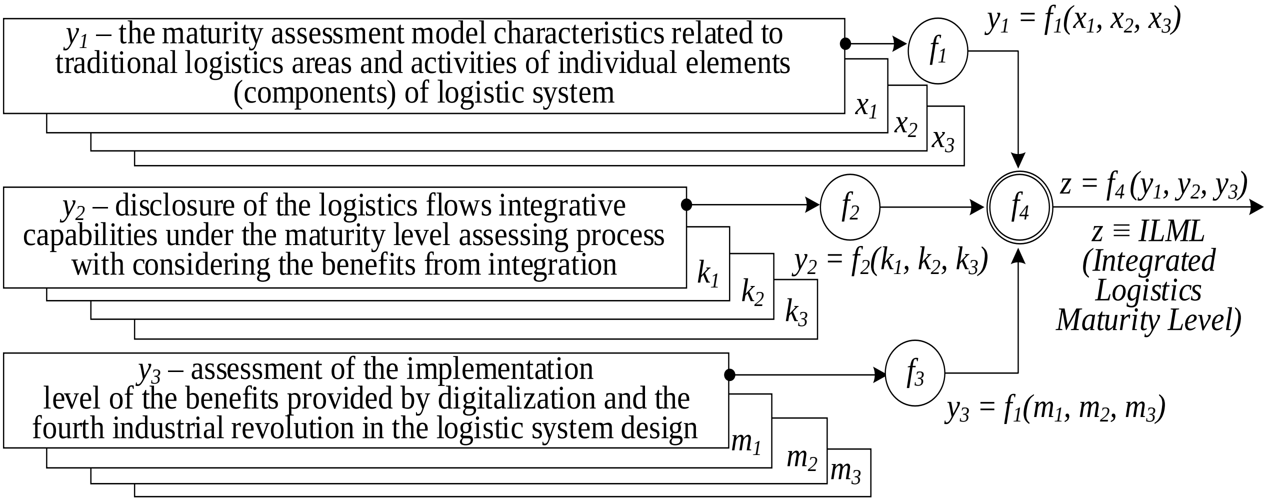
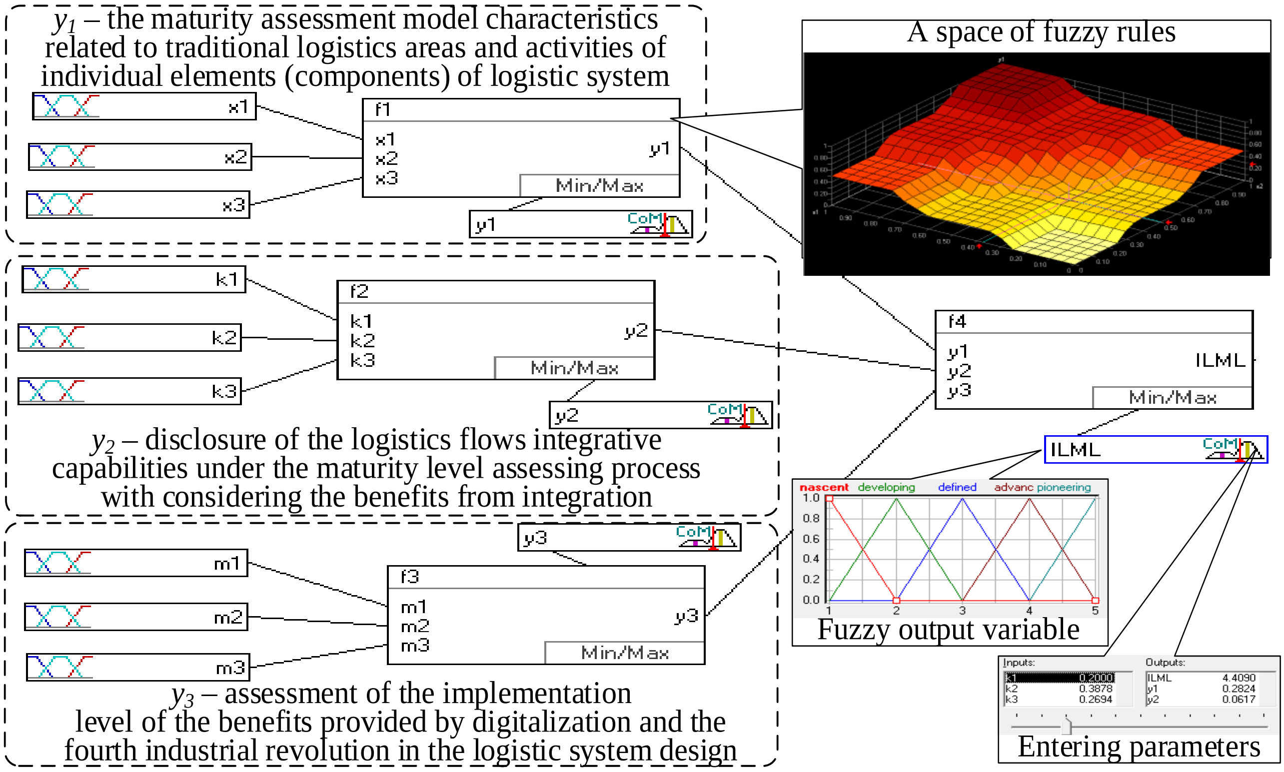



Fig 1. - The article hypothesis regarding direction for assessing the logistic system maturity level in integrated supply chains




A) Revealing the logic of forming a fuzzy logical conclusion




B) Implementing fuzzy inference with FuzzyTech

Fig. 2 – Fuzzy model for assessing the logistic system maturity level

The diagram presented in Fig. 2 comprises two parts, each serving a distinct role in the overall model. The first part (part A) elucidates the general logic of formulating a fuzzy logical inference concerning determining the logistic maturity level. This component provides an approach for the amalgamation of indicators for each of the groups presented in Fig. 1, thereby offering a comprehensive methodology for assessment. Part B of given at Fig. 2 diagram portrays the software implementation of the evaluation logic, utilizing a hypothetical example for illustration purposes. For this specific example, three indicators are selected for each group, ensuring a balanced representation across all categories. It should be noted that the symbolic representation of the indicator groups and the fuzzy inference functions in both the first and second parts of Fig. 2 are consistent. It can be seen that the terms of the output variable in Fig. 2 (ILML variable) correspond to their description in Table 2.

In addition to the elements detailed previously, Part B of Figure 2 also showcases the blocks of logical inference rules. Such rules' blocks (they correspond to the set of functions {f} from part A of Fig. 2|) are requisite for formulating robust logical inferences, providing the framework to manage and process raw data. The rules within each block can vary depending on the set of indicators as well as the specific characteristics of the integrated supply chain activities. The selection of fuzzy inference rules is facilitated by an adaptable framework that adjusts based on the unique aspects of each supply chain, ensuring that the evaluation remains accurate and relevant. Each rule can be elucidated as a corresponding plane for formulating fuzzy inference, visually representing the complex mathematical processes underlying the inference system. Additionally, within part B of Fig. 2, one can observe a module of the FuzzyTech program that calculates each individual assessment's influence on the resultant indicator, shedding light on the intricate interplay between individual metrics and the overall evaluation result.

Each of the maturity level indicators utilized in Figure 2 could potentially be represented by an aggregate of several indicators, thereby providing a more nuanced and comprehensive assessment of each maturity level. This approach would introduce an additional hierarchy level to the proposed maturity assessment model, containing its own set of fuzzy inference rules, enriching the evaluation process. Following, we delve into the types of indicators that could be employed for conducting a fuzzy evaluation of logistic maturity. The discussion will revolve around sets of indicators for each group, where a specific indicator could being selected from such a set. The choice of indicators, in this way, becomes a dynamic process, allowing for adjustments and refinements based on the unique characteristics of the evaluated logistic system, further enhancing the validity and reliability of the assessment.

So, let's consider the content presented in Fig. 2 sets of indicators and characteristics of the logistics maturity level. The following seems appropriate if we talk about aspects related to traditional logistics areas and activities of individual elements of the logistic system (components y1 at Fig. 2). Firstly, it is necessary to calculate process efficiency and effectiveness (subcomponent x1 at Fig. 2). As maturity model elements here could be used, the indicators such as order cycle time, inventory turnover, transportation costs, and order accuracy. Secondly, it is necessary to consider workforce development and skillset (subcomponent x2 at Fig. 2), which is filled with such indicators as an investment in employee training and development, skill-building programs, and the presence of specialized logistics talent. Finally, in this group of indicators, we will define the subcomponent (x3 at Fig. 2) of organizational culture and structure (degree of innovation, agility, and collaboration within the organization) and the presence of cross-functional teams and dedicated logistics personnel).

The next group of indicators for assessing logistics maturity (components y2 in Fig. 2) correlates with disclosing the logistics flow integrative capabilities. The key emphasis here is proposed to be on supply chain integration (k1 $\in$ {extent of collaboration and information sharing among supply chain partners, visibility and traceability of goods and information, seamless coordination of processes}), sustainability and environmental performance (k2 $\in$ {adoption of green logistics practices, energy efficiency, waste reduction, and carbon footprint}), and strategic alignment (k3 $\in${alignment of logistics goals and objectives with overall business strategy, prioritization of logistics initiatives based on strategic importance}).

Finally, last part of the maturity assessment model (components y3 in Fig. 2) dialing with assessment the benefits provided by digitalization and the fourth industrial revolution within the logistic system design. The key areas here are technology adoption, data-driven decision-making, and managing the digitalization risks. The first of these areas (subcomponent m1 at Fig. 2) of maturity estimation is revealed through the degree of Implementation and integration of advanced technologies such as IoT, AI, machine learning, blockchain, and robotic process automation (RPA). In the case of the data-driven decision-making area (subcomponent m2 at Fig. 2), it is possible to calculate the utilization of data analytics, predictive analytics, and real-time data for decision-making qualitatively, as well as the establishment of data governance policies and data management practices. The last areas connected to managing the digitalization risks (subcomponent m3 at Fig. 2) must be entered into the model the characteristics of risk management practices Implementation, ability to adapt to disruptions, adherence to service level agreements (SLAs), and supply chain resilience measures.

By evaluating the maturity level across given in Fig. 2 dimensions using the aforementioned indicators, organizations not only can gain a comprehensive understanding of their logistics system performance, but also can identify areas for improvement. Even though an integral assessment is employed, it is possible to utilize a more detailed representation of the evaluation results on logistic maturity. This exact representation enables a more granular understanding of the performance across various facets of logistic operations, provided in the form of a radar chart, as shown in Figure 3, where presented in Figure 2 directions have been matched. The radar chart provides a visual representation of performance across multiple criteria, efficiently identifying strengths and areas for improvement.

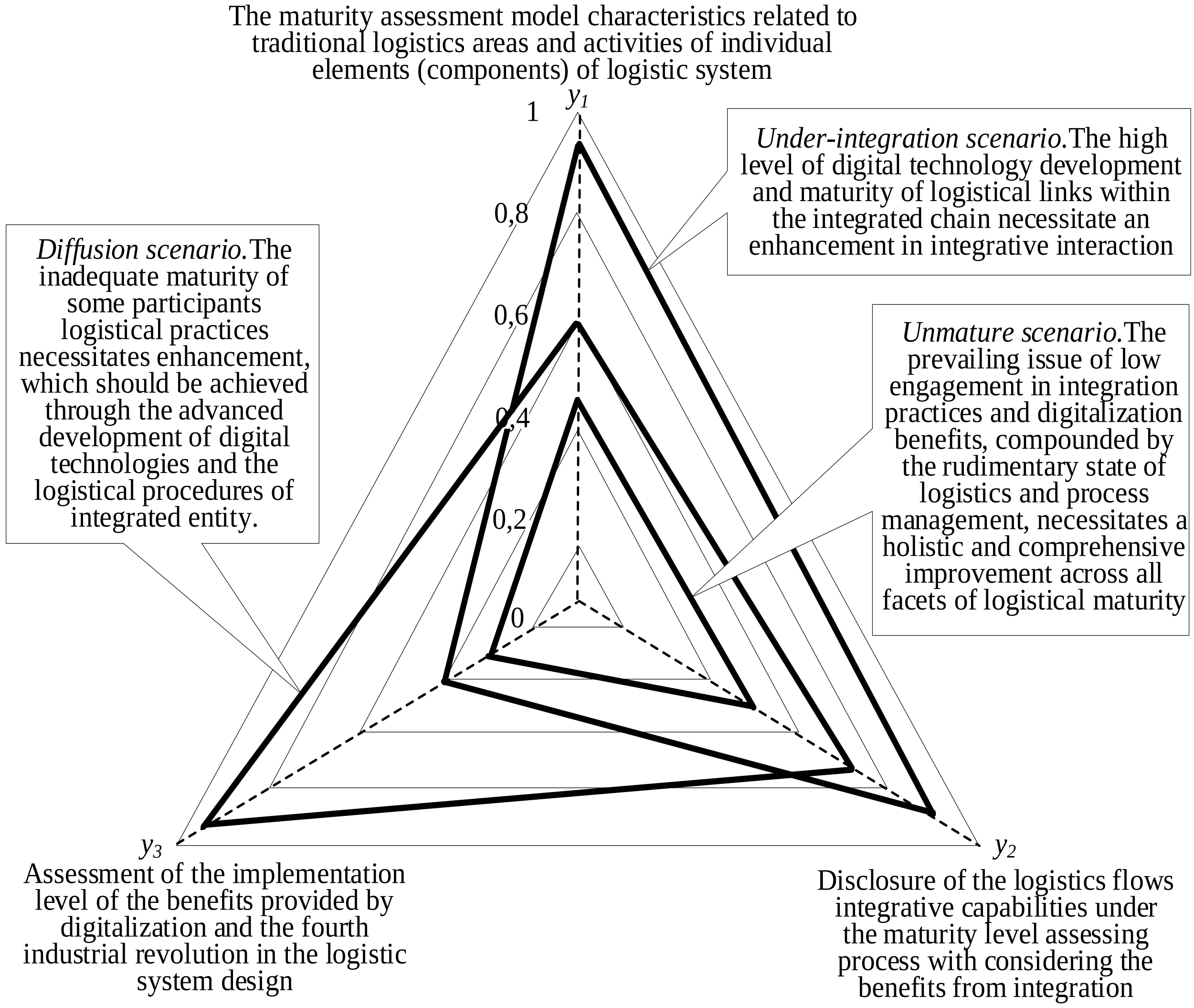



Fig. 3 – Response scenarios to logistic maturity assessment

As we can see, Fig. 3 contains descriptions of different enterprise response scenarios to the results of the logistic maturity evaluation. These scenarios provide a strategic perspective on possible actions and decisions that could be taken in response to the insights derived from the review, adding another layer of utility to the assessment process.

**Conclusions.** The fourth industrial revolution, distinguished by the convergence of digital, biological, and physical technologies, has catalyzed significant transformations in the logistics industry, giving rise to the Logistics 4.0 paradigm. Simultaneously, a compelling need has arisen for continuous investment in assessing and developing the maturity of logistics systems. Given this, an array of existing maturity assessment models designed for business systems has been analyzed, encapsulating their fundamental aspects and deliberating on their prospective metamorphosis in response to the burgeoning influence of digitalization. Based on this analysis results, three critical areas for evaluating logistics maturity in an integrated supply chain have been identified. These areas include the level of formalization within the integration process, the maturity of individual participants, and the utilization of opportunities provided by the fourth industrial revolution. By focusing on these crucial areas, companies can enhance logistics maturity, thus increasing the competitiveness of the integrated supply chain. Also, the article provides a comprehensive interpretation of the maturity level of integrated logistics systems, which are proposed to identify based on the developed hierarchical model of fuzzy inference. Under the fuzzy model, indicators for assessing different aspects of logistic maturity have been offered, and response scenarios to logistic maturity assessment results have been developed.

Notwithstanding the extensive and perspicacious nature of this research, there remain uncharted territories within the domain of logistic system maturity assessment, warranting further exploration and inquiry. Future research endeavors may delve into the development of industry-specific maturity models, investigate the impact of regional disparities on logistic maturity, or examine the role of sustainability and circular economy principles in the context of Logistic 4.0.

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