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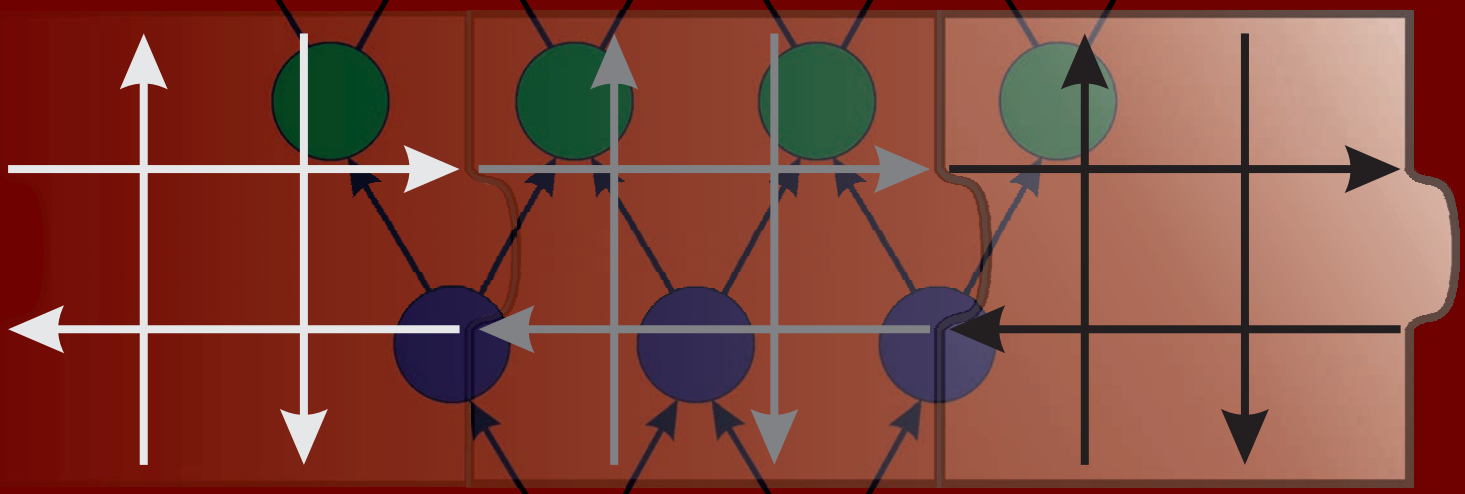

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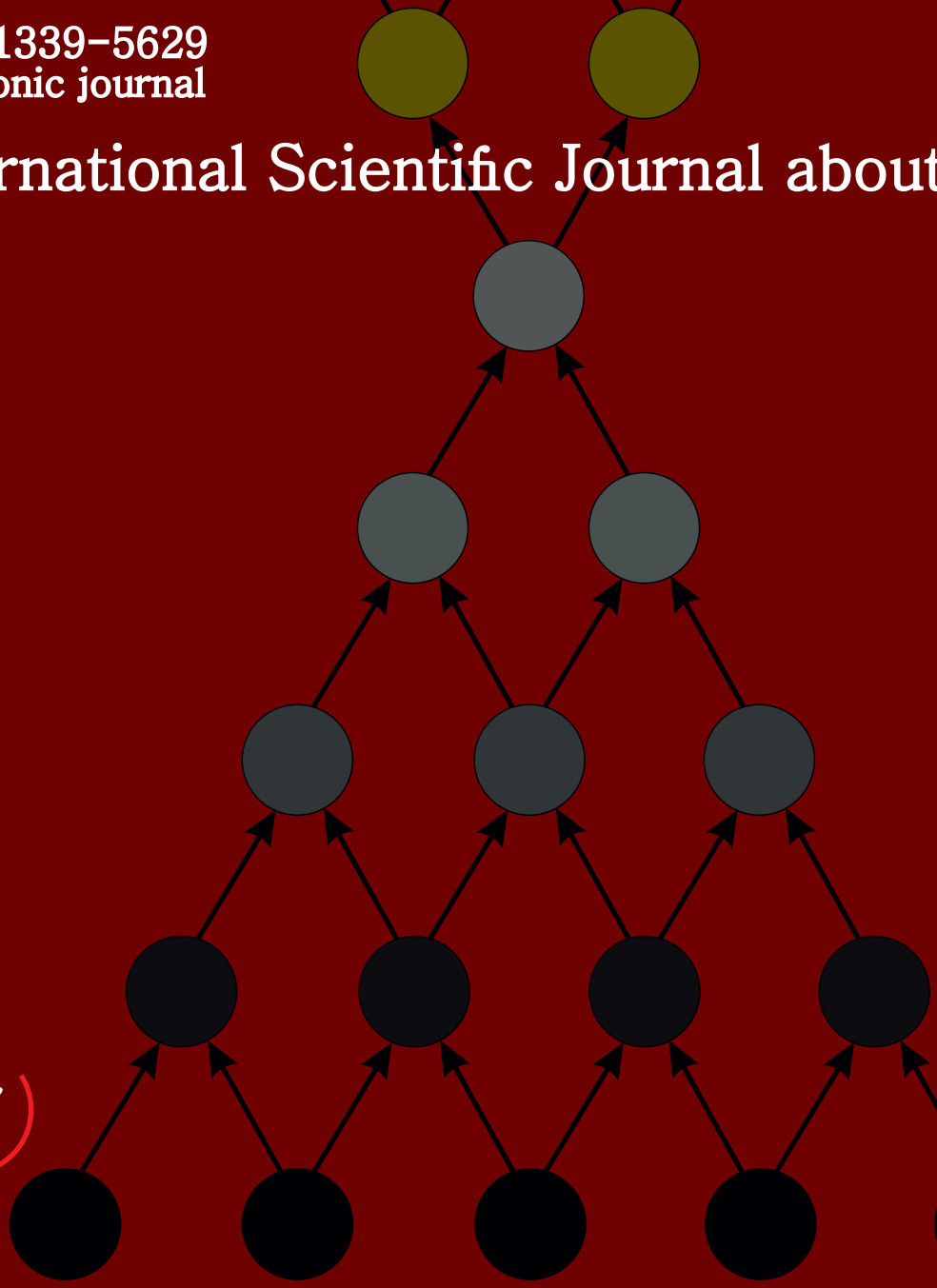

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Informal contracts' influence on shipping efficiency: a customer- perspective of package delivery agent

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Keywords: courier services, package delivery agents, informal contract, trust.
Abstract: Understanding the role of informal agreements can help delivery services prioritize customer preferences, leading to improved service quality and customer satisfaction. Unfortunately, where there are gaps either on general understanding of communication stand in-between the different of failure and success. This qualitative research study delves into the dynamics of informal contracts between customers and package delivery agents, and their impact on the efficiency of the shipping process. The research aims to gain a deeper understanding of how these unwritten agreements affect various aspects of the delivery process from both the customer and delivery agent viewpoints. Through in-depth interviews and thematic analysis, this study sheds light on the nuances of these informal arrangements and their role in shaping the overall shipping experience. The study revealed that informal agreements play a significant role in package delivery experiences. Participants described unspoken arrangements formed through trust and effective communication. Adherence to these agreements positively influenced service efficiency, with prioritized deliveries and improved accuracy. However, deviations from agreements led to emotional reactions such as frustration and disappointment, impacting the perceived trustworthiness of the delivery service. Additionally, the study highlighted cultural variations in the adoption of informal agreements and the importance of clear communication in establishing and maintaining these arrangements.

1 Introduction

The courier service represents the final and pivotal stage within the Internet shopping procedure [1]. Register Courier services frequently assumed the dual responsibility of packaging and transporting or delivering goods. The demand for courier services in Malaysia has witnessed a surge during Covid-19 pandemic [2]. The increasing need for shipping has played a significant role in the formation of numerous entities Courier services [3]. The current state of affairs has advanced to the extent where courier firms are now engaging in collaborations with agents. The agents are responsible for the transportation and delivery of packages, as facilitated by courier services. In Malaysia, agents refer to individuals or small groups who undertake the task of collecting parcels on behalf of courier services. These agents engage in a door-to-door approach to facilitate the delivery and collection of shipments. Subsequently, the package is transferred to a courier service for transportation, whereupon the individuals involved receive a remuneration from the courier service. Moreover, they generate a profit from their customers as well. The individuals in question lack a valid business license and mostly engage in transactions with their immediate social circle and relatives, or by affiliating themselves with different wholesale entities. Due to the high level of trust bestowed upon them by their consumers, the latter refrain from engaging in any formal contractual agreement when entrusting their items for delivery. Occasionally, these entities may generate sales for wholesale enterprises, whilst in other instances, they are employed for the purpose of facilitating the transportation of goods. Regardless of the circumstances, they are consistently valuable.

There is a lack of research on both the standard operating practices that these package delivery agents adhered to and their operation as a result of the fact that these package delivery agents are not registered and that their business does not follow any formal procedures. They also deliver their services on a "Informal Contract" basis, which is the fundamental reason why they do not yet have a standard operating procedure in place. Considering the potential problems that may result from "Informal Contracts" associated with package delivery services, problems include the possibility that packages may be delivered late, lost, damaged, or in the wrong location [4]. This study believes it is vital to analyse, from the customer's point of view, the shipping operation efficiency of package delivery agents who work on informal contracts in order to determine how effective their shipping operations are.

De Oliveira et al. [5] have demonstrated that in Brazil, despite the existence of legal regulations governing motorcycle courier activity, a considerable fraction of the workforce involved in this sector operates informally. The efficiency of motorcycle couriers is adversely affected by the imposition of delivery charges, suggesting that the

implementation of a fee-free delivery policy may provide favourable outcomes in terms of delivery performance and the overall count of motorcycle couriers. The implementation of training programs focused on financial and career management has the potential to enhance the productivity levels of motorcycle couriers. There is a need to establish trust when it comes to logistic operation [6]. Specifically, in delivery services, to the point where currently based on trust, drone-based package delivery logistics systems are produced [7-10]. Considering that their interest in optimizing package delivery service within the research communities. The main aim of this study is to examine the effects of informal contracts formed between package delivery service personnel and clients on the whole shipping process. The contemporary e-commerce environment has experienced a notable increase in the transportation of packages, and the contacts between clients and package delivery agents have emerged as crucial factors in influencing the effectiveness of the shipping procedure. Formal contracts are commonly employed to regulate business transactions, although the influence of informal agreements and implicit expectations is as noteworthy inside this sphere. The objectives of this study are:

To Investigate the Formation and Nature of Informal Contracts in Package Delivery Services

To Assess the Impact of Informal Contracts on Shipping Efficiency and Customer Satisfaction

These two objectives of study would synergistically contribute to a holistic comprehension of the role and impact of informal contracts in the package delivery process. The primary aim of the initial objective is to examine the fundamental mechanisms that underpin these agreements. Conversely, the subsequent objective aims to explore the tangible consequences and ramifications that these agreements have on the diverse players engaged in the shipping process.

2 Theoretical framework

There exist numerous theories pertaining to the concept of "Informal Contract." When examining its application in the context of package delivery services, as well as the agents involved in facilitating these services and their customers, additional theories emerge that elucidate the potential impact and provide a practical framework for implementation. Given the purpose of adopting theories to facilitate the attainment of specified research objectives, this study aims to select theories that align with their potential to contribute to the realization of the suggested research objectives. Therefore, in order to accomplish the two research objectives pertaining to the impact of informal contracts on shipping efficiency from the standpoint of customer-package delivery agents, it is necessary to consider several theories from diverse fields.

Regarding the study's objective 1, which pertains to the examination of the development and characteristics of informal contracts in package delivery services, the theories employed include the "Social Contract Theory," "Communication Theories," and "Trust Theory." The rationale behind the adoption of theories stems from the fact that the "Social Contract Theory" delves into the tacit agreements and standards that regulate interactions within a given society [11]. The concept can offer a theoretical structure for comprehending the emergence of informal contracts as unexpressed agreements rooted on commonly held cultural norms [12]. In a similar vein, the field of "Communication Theories" provides insights into the processes by which participants in communicative exchanges transmit and interpret messages [13]. Understanding how clients and delivery agents negotiate and develop informal agreements is crucial in this context [14]. The concept of "Trust Theory" posits the framework of "Trustworthiness-Trust-Credibility" as a means to elucidate the process of establishing and sustaining trust within interpersonal connections [15]. The examination of trust's role in the establishment of informal contracts holds significant relevance in comprehending this phenomenon [16].

Regarding research objective 2, the assessment of the impact of Informal Contracts on shipping efficiency and customer satisfaction incorporates the utilization of several theories. These theories include "Service Quality Theories," "Expectancy Disconfirmation Theory," "Agency Theory," and "Behavioural Economics Theories." The rationale behind the adoption of these theories stems from their ability to evaluate service quality characteristics and customer happiness, as evidenced by the Service Quality Theories [17]. The approach presented herein offers a theoretical lens through which to examine the potential influence of informal contracts on key dimensions such as responsiveness, reliability, and assurance within the context of package delivery services. [18] The concept of "Expectancy Disconfirmation Theory" elucidates the process by which customers develop evaluations of satisfaction by comparing the disparity between their initial expectations and the subsequent real experiences [19-20]. This study aims to investigate the impact of adherence to informal contracts on customer satisfaction. Moreover, the concept of "Agency Theory" serves to investigate the dynamics of the principal-agent interaction and its use in analysing the impact of informal contracts on the behaviour of customers and delivery workers [21]. The utilization of this approach facilitates the examination of matters such as moral hazard and the extent to which informal agreements effectively align incentives [22]. The concept of "Cultural Theories" pertains to the study of culture and its characteristics, aiming to elucidate the influence of cultural elements on the perception and realization of informal contracts, particularly in cross-cultural settings [23]. The theories of "Behavioural Economics" offer valuable insights into the decision-making processes of individuals when faced with unclear circumstances [24]. This aspect holds significance in comprehending the impact of informal contracts on decision-making within the realm of delivery interactions.

These theories can be employed in conjunction with each study objective to build a comprehensive theoretical framework that guides the research design, data collection, analysis, and interpretation of results. The aforementioned findings serve to situate the research within the existing scholarly literature, providing insights into the complex dynamics related to informal contracts and their impact on shipping effectiveness and customer contentment.

While a multitude of causes can conceivably be associated with these research. The theories employed in this study are oriented towards achieving the research aims. Other theoretical frameworks that can be associated with the examination of the influence of informal contracts on shipping efficiency, particularly from the perspective of customer-package delivery agents, encompass "E-commerce and Logistics theory" and "Customer-Service Provider Interactions". The academic discipline of "E-commerce and Logistics theory" has established a robust framework for examining the overarching trends in the growth of e-commerce and the simultaneous advancement of logistics and package delivery services [25]. This study comprises an examination of the challenges encountered in the final stage of delivery, sometimes referred to as last-mile delivery. It also investigates the preferences and demands of customers in relation to this aspect of the delivery process. Furthermore, it explores the role and impact of delivery agents within the larger e-commerce ecosystem. The theoretical framework referred to as "Customer-Service Provider Interactions" has been created to analyze the intricacies of communication, customer contentment, and the determinants that impact the overall delivery experience, particularly in the realm of delivery services [26].

Conducting research on service quality, efficiency, and customer perceptions in the logistics and delivery industry can provide significant insights into the multifaceted factors that impact the overall delivery process. This may involve inquiries regarding the efficacy of delivery velocity, accuracy, tracking systems, and the influence of technology within the given framework. The investigation into trust-building strategies between clients and delivery agents is of considerable importance in the present setting [27]. The examination of the initiation and perpetuation of trust in delivery interactions, together with its implications for the efficacy and proficiency of deliveries, has considerable academic importance. The incorporation of cultural and sociological elements in research provides a more holistic framework for understanding the impact of informal agreements on customer expectations and the conduct of delivery agents. It is crucial to do an analysis of the legal and ethical aspects pertaining to informal contracts within the domain of electronic commerce and the transportation of goods. This may entail discussions regarding consumer rights, duties, and obligations. Studies that focus on the customer experience, satisfaction, and their perceptions of service quality during delivery interactions have the potential to offer useful insights into the impact of informal agreements on their overall level of satisfaction [28]. The examination of the human-centric aspects of logistics and delivery services, encompassing the importance of empathy, communication, and personalized encounters, holds promise for providing a holistic comprehension of the ramifications of informal agreements. By utilizing qualitative research methodologies within the fields of consumer behaviour and service interactions, relevant studies can provide useful insights into the subjective experiences, feelings, and motivations demonstrated by both consumers and delivery employees.

3 Research methodology

The qualitative research methodology is a research approach that prioritizes the comprehension and interpretation of the fundamental meanings, patterns, and intricacies of human behaviour, experiences, and social phenomena. Qualitative research is predicated upon the use of non-numerical data, encompassing textual information, visual representations, direct observations, and interviews, in order to comprehensively investigate the intricacies and depth of a certain subject matter [29-30]. The research methodology employed in this study is qualitative in nature, aiming to explore and gain insights into the intricate viewpoints, experiences, and behaviours of consumers and package delivery workers. Specifically, the focus is on understanding the impact of informal contracts on shipping efficiency. The research methodology utilizes many methodologies, including in-depth interviews, open-ended surveys, and thematic analysis, in order to gather comprehensive qualitative data. The objective of this research is to elucidate the fundamental motivations, emotions, and social dynamics that influence the establishment of informal contracts and their consequences on many facets of the package delivery procedure. This study aims to employ qualitative research methods in order to gain a comprehensive and profound comprehension of the intricate dynamics and subjective perceptions pertaining to informal agreements within the shipping industry.

3.1 Research design

The present study utilizes a qualitative research approach, facilitating a comprehensive examination of the complex dynamics associated with informal contracts. Qualitative research is well-suited for comprehending the subjective experiences and viewpoints of persons.

3.1.1 Population of the study and sampling

Given that this study is qualitative in nature, it necessitates a limited number of representative individuals from a given community. Typically, the population under study is estimated and pertains to the total number of individuals or topics being examined. The procedure of estimating the study population involves the identification of potential participants who are individuals employed as package delivery agents, as well as their consumers. In

particular, those situated inside the Malaysian environment, whether residing in Malaysia or utilizing Malaysian delivery services for the transportation of their packages either from Malaysia to any location or from any location to Malaysia. The topic under consideration holds significance in relation to the research problem.

The determination of sample size in qualitative research is guided by the "Principle of Theoretical Saturation." The concept of theoretical saturation can serve as a valuable framework for doing qualitative research. Empirical evidence suggests that in certain situations, a sample size of 12 may be sufficient to achieve data saturation within a generally homogeneous community [31]. According to Hennink and Kaiser [32], the point of saturation was achieved with a range of 9-17 interviews or 4-8 focus group talks. In a phenomenological study, Creswell [33] suggested conducting between 5 and 25 interviews, while for a grounded theory study, a range of 20-30 interviews was advised. Based on the aforementioned recommendations, the present study has successfully recruited a sample size of 10 participants for the interview. There are ten individuals who serve as package delivery services agents, while six individuals assume the role of customers for these delivery agents. All clients who participated in the study got package deliveries from delivery agents representing different service providers. Therefore, this particular technique is referred to as purposive sampling, which is employed to guarantee the inclusion of a diverse variety of experiences.

3.1.2 Development of interview questions

The interview question is specifically designed to align with and serve as a subset of the study objectives. Therefore, two sets of interview questions have been devised to gather data that will fulfill both research objectives 1 and 2. All of the questions included in the study are open-ended in nature and have been subjected to a rigorous validation process involving three subject matter experts. As a result, a collection of interview questions that have undergone validation and correction was later generated (refer to Table 1 and Table 2).

Table 1 The research interview questions map to respective research objectives

	Research Objective 1 Interview Questions: Investigate the Formation and Nature of Informal Contracts	**Research Objective 2 Interview Questions:** Assess the Impact of Informal Contracts on Shipping Efficiency and Customer Satisfaction
	Expected Theme: *Formation of Informal Contracts*	**Expected Theme:** *Impact on Shipping Efficiency*
1	Could you provide an analysis of tacit agreements between clients and delivery agents? What were the specific terms that were involved in the matter under consideration?	Have you observed variations in the rate of delivery and level of precision in relation to the existence of informal agreements? What is the impact of these factors on one's level of satisfaction?
2	What is the role of communication in the establishment of informal contracts? Please provide instances when communication has influenced these agreements.	What is the effect of adhering to or deviating from an informal agreement on one's emotional experience during delivery?
3	The present inquiry seeks to examine the various aspects that lead to the establishment of trust between consumers and delivery agents. Additionally, this investigation aims to explore the relationship between trust and informal contracts.	What is the impact of informal agreements on the communication dynamics between consumers and delivery agents?
4	What is the influence of cultural or environmental elements on the interpretation of informal agreements in package deliveries?	Could you please provide an example of a situation in which a departure from an informal agreement led to discontentment? What were the circumstances that led to this occurrence?
5	Are there variations in informal agreements among different sorts of products? What is the influence of this on their formation?	To what extent can informal agreements impact the perception of predictability and reliability within the delivery process?
6	Illustrate cases in which informal agreements were not honored. What were the underlying factors that contributed to these outcomes, and in what ways did they influence your cognitive interpretation?	What is the impact of informal agreements on the probability of future utilization of the same delivery service provider?
7	What is your perception of the negotiation process involved in these informal agreements? Are there variations in the expectations?	Could you please cite instances that illustrate the influence of adhering to informal agreements on one's overall trust in the delivery agent and provider?
8	To what extent do prior interactions with agents or providers shape individuals' expectations and the establishment of informal agreements?	How can informal agreements impact one's capacity to offer feedback or express issues regarding the delivery process?

The research approach employed in this study entails the use of in-depth semi-structured interviews with self-initiated expatriates, human resource managers, and organizational executives. The interview questions focus on the participants' personal experiences, their perspectives of package delivery services, and the influence of informal contracts in relation to the behaviours they have encountered. The interview questions are well aligned with the established study objectives. Consequently, considering the two research inquiries that have been presented, a series of interview inquiries was produced for each of them. Likewise, the forthcoming themes that are predicted to emerge following the completion of data collection for both the research goal 1 questions and research objective 2 questions have been formulated. The framework for research question 1 is to investigate individuals' perceptions regarding the establishment and characteristics of informal contracts. The objective of study question 2 is to investigate the perception regarding the influence of Informal contract on shipment efficiency and customer satisfaction.

3.1.3 Data collection

The primary method employed for data collecting in this study is the utilization of interviews. The interview process encompasses a sequence of procedures aimed at actively involving participants, collecting data, and acquiring a deeper understanding of their experiences and viewpoints. This will enable the study to capture the perception of informal contracts within the specific setting of package deliveries. The utilization of interviews in this context offers a valuable opportunity to delve into emerging themes and foster an environment where participants are encouraged to divulge their individual narratives. The interviews were performed with each and every participant. The individuals who met the research objectives and sampling criteria were contacted by telephone and face-to-face communication methods. They were provided with an introduction and explanation of the study's purpose, and were asked to participate.

Prior to conducting the interview, the researchers furnish the participants with a consent document that delineates the study's objectives, the interview methodology, the participants' entitlements, and the safeguards implemented to ensure confidentiality. All participants thoroughly read and comprehended the contents of the consent form, and afterwards provided their signature as an indication of their voluntary agreement to participate in the study. All interviews were conducted utilizing an online platform, with each participant conducting their interview at a different time. The participants have reached a consensus to record the interviews in order to assure precise transcription at a later stage.

3.2 Data analysis

Thematic analysis was employed as a methodological approach to discern and ascertain repeating patterns, themes, and categories within the dataset obtained from the interviews. The analytical method encompasses a series of iterative stages that include coding, categorization, and topic development. Table 2 presents the main topic "formation of informal contracts" together with the significant subthemes that have emerged, the linked quotations, and the coding created for this study.

Table 2 The analytical extractions of the findings main theme "formation of informal contracts"

	Subthemes	**Sample Quotations**	**Code**
1	Some examples of informal deals and the terms of those agreements.	"I remember once leaving the package with neighbor when customer was out of town."	we find mutual understanding
2	How communication affects the way informal deals are made.	"When I inquired... it was a foregone conclusion."	Effective negotiation through communication
3	How trust and making informal deals are related.	"Trust is crucial... reliable."	Trust enhancing informal agreements
4	Culture has an effect on how informal deals are interpreted.	Cultural differences are less frequent.	Cultural influence on agreement norms
5	How different kinds of products affect making informal deals.	"For fragile items... an unspoken rule."	Item-specific agreement nuances
6	What people think when informal deals are broken.	Once the product is complete... commitment to these agreements ends.	Trust end by breaching agreements
7	A participant's view on how informal deals are negotiated.	"I've discovered... ensures a smooth operation."	Agreement negotiation dynamics
8	How events from the past affect making informal agreements.	"I had a great... without a formal agreement."	Agreements shaped by historical experiences.

In a similar vein, the primary themes of "Impact on Shipping Efficiency" have given rise to several significant subthemes. This study has identified and presented these subthemes, together with the corresponding quotations and the coding system employed, in Table 3.

Table 3 The analytical extractions of the findings main theme "impact on shipping efficiency"

	Subthemes	Sample Quotations	Code
1	informal deals affect how fast and happy customers are with delivery.	"It's like they prioritize... stick to it."	Improved service and contentment
2	Emotional experience tied to whether or not informal deals are kept or broken.	"When the delivery agent... trust we built was broken."	Emotional impact of agreement outcomes
3	informal deals change the way people talk to each other.	"Having a clear agreement... focused... efficient."	Structured and focused communication
4	Unhappy because an informal deal wasn't kept.	"I wasn't home... it was raining... disappointed."	Disappointment due to agreement breach
5	Informal deals have made things more predictable and reliable.	"When there's an agreement... secure."	Increased reliability and confidence
6	informal deals affect the choice of service provider in the future.	"When they respect our agreements... choose them again."	Positive experience shaping loyalty
7	Trust is increased when people stick to informal deals.	"When the delivery agent fulfills... care about delivering a good service."	Trust enhancement through agreement fulfillment
8	informal agreements supply feedback	"I didn't want to complain... awkward for future deliveries."	Feedback reluctance due to agreements

4 Presentation of the results and discussion

In the context of qualitative research, it is common practice to condense the fundamental aspects of participants' experiences and viewpoints into concise sentences that effectively capture the key themes of their responses. These interpreted statements offer a framework for comprehending the subtleties and complexities of the research goals. This essay explores the interpreted phrases that are formed from interview responses, emphasizing the valuable insights that can be obtained from these condensed formulations.

4.1 The principal finding on the formation and nature of informal contracts

The primary finding pertaining to the first study's objective centers around the concepts of "Mutual Understanding and Arrangement (MUA)", "Effective Negotiation through Communication (ENC)", and "Trust Enhancing Informal Agreements (TEIA)" as the ultimate themes after undergoing pre-processing. The acronym MUA refers to the concept of mutual understanding and arrangement, which commonly serves as the foundation for the establishment of informal contracts between clients and delivery agents. This situation illustrates the implicit but mutually understood agreements that evolve over a period of time, embodying the confidence and dependability that parties attribute to such arrangements. This highlights the significance of communication, encompassing both verbal and nonverbal forms, in facilitating such agreements, thereby guaranteeing the fulfilment of client wishes even in the absence of formal written records. The significance of communication in influencing informal agreements is emphasized by ENC. The experiences of the participants highlight the significance of excellent communication in facilitating the negotiation process. The concept of Effective Communication and Negotiation (ENC) posits that when customers effectively express their preferences and delivery personnel duly acknowledge them, it fosters a tacit agreement that manifests a mutual comprehension. This approach provides insight into the underlying processes of negotiation that extend beyond the apparent terms. The concept of TEIA refers to the dynamic relationship between trust and informal agreements. The participants place significant emphasis on the notion that trust plays a pivotal role in the establishment of these agreements. Customers establish a perception of dependability that extends beyond basic transactions by confiding in delivery personnel with their items and preferences. The aforementioned expression denotes that the existence of trust amplifies the inclination of individuals to partake in implicit agreements, hence facilitating more seamless interactions.

Among some of the key perceptions of the participant on Informal contract instances and the terms involved, one participant reveals that:

"Yes, we agreed that if I'm not home, they could leave the package with my neighbor. We never really talked about it, but it's kind of become a rule. They agreed to leave it next door and leave me a note in my mailbox."

This shows that an informal contract can be made even if there isn't a written deal. Instead, it's more like a mutual understanding that has grown over time. As part of the deal, the package will be left next door and the customer will be told by a note left in their mailbox. This arrangement shows how trust and familiarity can lead to a practical agreement that makes it easier to give something when the recipient isn't around. Also, when it came to how delivery agents and their customers communicated about informal contracts for no-delivery services, one responder said that:

"It's important to talk. Once, I asked if they could deliver after 6 PM, and the service person said yes. Since

then, they text me every time I get a package to confirm the time. It's like an unwritten agreement that we've made by talking things out."

This shows that good communication is very important in this situation. Because of this, the person delivering the packages now sends a text message to the customer to confirm when the package will be delivered. This unspoken agreement, which was made possible by clear communication, shows how a shared understanding has been reached, making arrival times more accurate and in sync. Also, when asked about the things that help customers and delivery workers build trust and how trust relates to informal contracts, some respondents gave similar answers. One of them said,

"Trust is very important in this process. We trust them more the more times they've done what we've asked. It works both ways, and when we trust them to do what we ask, we're more likely to make these informal deals with them because we know they'll keep to them".

This shows that trust is an important part of delivering packages. It says that trust between the sender and the receiver grows as the delivery people always follow the recipient's wishes. When people trust each other, they can make informal deals. It's the idea that if they trust the delivery people to do what they ask; they'll be more likely to go along with these unspoken agreements because they know the delivery people will listen to their wishes. Lastly, one respondent says this about the role of cultural or contextual factors:

"Cultural factors do play a part. I noticed that leaving a package with a neighbour wasn't as usual when I was abroad. So, it really depends on how people in that place do things. It might not be as common in all places."

This shows that different cultures have an effect on the way people leave items with their neighbours. It might not be accepted by everyone. Leaving a package with a neighbour might not be as usual in other places. This happens more or less often depending on cultural norms and local habits. This shows how important it is to think about cultural factors when trying to understand why informal agreements are used for package deliveries.

Theories can be linked to the finding. It was shown that "Mutual Understanding and Arrangement" is a map to "Social Contract Theory" The Social Contract Theory says that people in a society make unspoken deals to work together for the good of all. This idea fits with the words "Mutual Understanding and Arrangement." People involved in the delivery process make deals that aren't said out loud but are similar to social contracts. The theory helps reach the goal of the study by giving a framework for figuring out how mutual benefits, trust, and shared expectations lead to informal agreements. By using Social Contract Theory, researchers can learn more about the reasons, rules, and underlying principles that lead these unspoken agreements.

"Effective Negotiation Through Communication" is a link to "Communication Theories" Communication theories explain how successful communication shapes how people interact with each other. In the context of "Effective Negotiation through Communication," these theories help reach the study goal by showing how shared meaning, clarity, and understanding are key to making informal agreements work. When researchers use Communication Theories, they can look at how people talk about their views, negotiate terms, and come to agreements through good communication, which leads to the formation of unspoken contracts.

"Trust Enhancing Informal Agreements" is a map to "Trust Theory" Trust Theory focuses on how trust affects how people deal with each other and with the world. In the context of "Trust Enhancing Informal Agreements," this theory helps reach the goal of the study by explaining how trust is the basis for these agreements. This phrase makes it clear that trust is important for unspoken deals to work. By using Trust Theory, researchers can find out what makes people trust each other, what role past events play, and how trust affects how willing people are to sign informal contracts.

4.2 The principal finding on the impact of informal contracts on shipping efficiency and customer satisfactions

As the final themes, "Improved Service and Contentment (ISC)," "Emotional Impact of Agreement Outcomes (EIAO)," and "Structured and Focused Communication (SFC)" are the most important results of study objective 2. In terms of ISC, it shows how informal deals affect how well shipping works and how happy customers are. By sticking to informal agreements, delivery workers make sure that certain customer preferences are given the most attention. This leads to better service, higher speed, and, in the end, happy customers. The phrase shows that informal deals aren't just about keeping to the terms of the agreement, but also about giving the customer what they want. EIAO shows how informal deals can have an emotional side. It emphasizes that these deals have a direct effect on how the people involved feel. When people follow or break informal deals, it makes them feel something, which affects how they think the service is and how trustworthy the provider is. This way of looking at it stresses how important these agreements are in shaping how customers feel about the delivery process. SFC shows how informal deals affect how people talk to each other. Participants say that these agreements structure their relationships and help them talk about things that have to do with delivery. The phrase emphasizes that informal agreements make communication easier, making sure that talks are purposeful and in line with what's expected in terms of delivery. This, in turn, makes work more efficient.

One responder said,

"Definitely. When we have a deal, they seem to give my packages more attention. They try to follow the rules we've set up, which makes things much faster and more accurate. It makes me feel better and makes me more happy with their service."

This suggests that an informal understanding has a clear effect on how the delivery service treats the packages of customers. With a deal in place, it seems like the delivery service pays extra attention to the packages of customers. The delivery agents try hard to follow the rules that have been agreed upon by both parties. This makes deliveries happen faster and more accurately. This level of commitment and adherence to the rules gives customers a feeling of security and satisfaction, which makes their overall experience with the service a good one. In a similar way, one respondent said,

"One time they didn't follow the deal, and it was frustrating. I thought they would leave it with my friend, but they left it on my porch instead, where it got wet in the rain. It felt like the trust we had built up had been broken, and I was very upset."

This suggests that breaking the agreement made people unhappy, especially if the customers had counted on the delivery workers to keep their end of the deal. When they didn't, they were disappointed. The situation showed how important trust is in these kinds of arrangements and how its loss can lead to bad feelings. On the other hand, one respondent said this about the effect of informal agreements on how customers and delivery agents talk to each other:

"Having a clear understanding sets the tone for our conversations. I know what to expect, and they know what is important to me. So, we can talk to each other more clearly and effectively. It seems like we've always been on the same page."

This suggests that when customers and delivery agents have a clear agreement, it has a good effect on how they talk to each other. This clear understanding sets up a way for people to talk to each other. The customer knows what to expect, and the service people know what's most important to the customer. So, they can talk to each other in a more focused and efficient way. This shared understanding makes it easier for the two people to talk in a way that gets to the point. It's almost as if both sides start their interactions with the same idea, which makes dialogue easier and more effective. From a different point of view, one respondent said,

"It was frustrating to be disappointed, even if it was fixed later, because at first you feel like everything is over and there's nothing you can do about it."

This shows that initial sadness makes people feel like they've lost control and can't do anything about the situation. The customer says that the first feeling of sadness is so strong and overwhelming that it overshadows the fact that the problem was eventually fixed. This idea shows how the effects of emotional reactions can last even after problems are solved. "Improved Service and Contentment" maps to "E-commerce and Logistics Theory." "E-commerce and Logistics Theory" is especially important to "Improved Service and Contentment." This idea is about how to improve the customer experience by making the supply chain work better. For this study goal, it helps to understand how following informal agreements can improve service efficiency by making the delivery process run more smoothly. By studying the principles of logistics efficiency, researchers can figure out how keeping deals helps make deliveries faster and more accurate, which matches what people expect and makes them happier overall.

"Emotional Impact of Agreement Outcomes" is a map to "Affective Events Theory" The Affective Events Theory fits well with the term "Emotional Impact of Agreement Outcomes." This theory says that events cause emotional reactions, which then change how people act. For this study goal, the Affective Events Theory helps researchers understand how emotional responses are caused by sticking to or breaking informal agreements. Researchers can find out how people feel when their expectations are met, surpassed, or not met because of agreement results. This helps us understand how these feelings affect loyalty, future actions, and total interactions between customers and service providers.

"Customer-Service Provider Interactions" is a link to "Structured and Focused Communication." The idea of "Customer-Service Provider Interactions" fits perfectly with the phrase "Structured and Focused Communication." This theory looks at what happens when customers and service companies talk to each other. For this study goal, it helps to understand by showing how informal agreements structure how people talk to each other. Researchers can look at how the agreements guide the conversations of the people involved, making sure that the talks stay on delivery-related topics. When you know how these communication patterns work, you can see how efficient, focused conversations lead to better service.

5 Conclusion

In summary, this study explored the intricate realm of informal agreements established between package delivery agents and consumers, revealing a multifaceted network encompassing trust, communication, emotions, and service

effectiveness. By conducting interviews and performing analysis, this study has provided insights into the genesis, impact, and dynamics of these implicit agreements, thereby enhancing our comprehension of their significance within the contemporary package delivery industry. The results revealed two notable research aims. Initially, the examination of the establishment and characteristics of these informal contracts revealed the significance of mutual comprehension, effective communication, and cultural subtleties in developing these arrangements. The participants recounted situations in which trust and familiarity facilitated the development of implicit understandings, obviating the necessity for explicit conversations. The importance of efficient communication has been identified as a crucial factor in the establishment of these agreements, serving as a means to negotiate preferences, terms, and expectations. Furthermore, the evaluation of the influence of informal contracts on the efficiency of shipping operations and the satisfaction of customers highlighted the interconnectedness between the adherence to contractual agreements and the quality of service provided. The participants provided accounts of situations in which these agreements resulted in the prioritization of delivery, precise implementation, and increased levels of satisfaction. On the other hand, when there were deviations from these agreements, it elicited intense emotional responses, highlighting the delicate nature of trust between customers and service providers. The findings of this study have broader ramifications that beyond the domain of package delivery. The authors place significant emphasis on the significance of establishing and sustaining trust within service encounters, while also noting the influence of cultural diversity and recognizing the emotional aspects of customer experiences. This study functions as a persuasive appeal for delivery services to give priority to client preferences, allocate resources towards effective communication techniques, and swiftly rectify any deviations in order to cultivate enduring connections. As this exploration of informal agreements in the realm of package delivery draws to a close, it becomes apparent that these implicit arrangements extend beyond simply logistical considerations. These entities symbolize the intricate fabric of human engagements, intricately intertwined with elements such as trust, anticipation, and communication. By acknowledging the importance of these insights and implementing corresponding actions, service providers can initiate a journey towards providing customized, streamlined, and emotionally impactful experiences that surpass mere package delivery and establish enduring relationships with their clientele.

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Sustainable public procurement for supply chain resilience and competitive advantage
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Sustainable public procurement for supply chain resilience and competitive advantage

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Keywords: sustainable public procurement, resilient supply chains, supply chain disruptions, e-procurement, life cycle.
Abstract: Public procurement plays a crucial role in national economies, as it represents a significant share of public spending. Governments can thus use this considerable purchasing power to promote environmental sustainability, social responsibility, and economic efficiency, while encouraging the supplier market to innovate and adopt more sustainable practices to remain competitive, and to generate more resilient supply chains. Given the interdisciplinary nature of the subject of sustainable public procurement (SPP), the documentation is abundant and diverse, hence the need for an updated literature review especially in the aftermath of the COVID-19 crisis period. This article consists of a systematic literature review focusing on articles with an empirical approach. The results reveal, among other things, 8 main research themes subdivided into 19 sub-themes, with a dominance of literature on the obstacles and incentives related to the implementation of SPP, while those concerning e-procurement and the analysis of the social life cycle remain relatively limited. The study also underscores the role of local economies and SMEs in public procurement strategies. It highlights a trend towards geographical diversification, indicating the global significance of SPP, with noticeable differences in adoption between developed and developing countries. The review calls for future research to focus on developing practical frameworks and tools for integrating sustainability more comprehensively in public procurement. The findings illuminate the pivotal role of SPP as a mechanism steering societies towards a sustainable, resilient, and equitable future, particularly in a post-pandemic world.

1 Introduction

The COVID-19 crisis represents one of the rare instances of supply chain disruptions that have devastated the global economy. The pandemic surge led to border closures, restrictions in air transport networks, limited raw material supplies, and the shutdown of several production units. Therefore, increased vigilance and adaptability are required in the future to reduce the risk of potential supply chain disruptions and to mitigate their consequences. This involves designing more resilient supply chains, less vulnerable to disturbances, and capable of adapting their behaviour to enable companies within them to respond to disruptions quickly and cost-effectively, for a return to normal functioning or possibly to superior performance. This is particularly crucial for supply chains involving the public sector, as it is often the largest procurer within a country. Consequently, the COVID-19 pandemic has imposed additional responsibilities on public procurement (PP) actors to ensure the continuity of public services and citizens' wellbeing, as well as responding to growing demands for increased resilience, fostering innovation, and promoting sustainability.

Sustainable public procurement (SPP) refers to the practice of public bodies acquiring goods, services, and works, while considering the environmental, social, and economic impacts associated with them. This adds complexity to the traditional procurement process in the public sector, which is based on selecting the lowest bid, especially when significant importance is given to non-monetary criteria. Then, it is particularly pertinent to conduct an updated literature review on SPP, especially in the aftermath of the COVID-19 pandemic period. This approach would allow an examination of whether and how the *intellectual territory* in this field has evolved in response to the new parameters and challenges imposed by the crisis.

The present paper involves conducting a state-of-the-art review of the theme of SPP, by answering the research questions: RQ1: What research has been conducted on SPP? RQ 2: What issues have been raised? RQ 3: How has the COVID-19 crisis impacted the literature on SPP research? RQ 4: What conclusions can be drawn regarding the exploration of opportunities for future research?

This article stands as a novel contribution to the nexus of knowledge on SPP, as it embodies the most current and comprehensive effort to synthesize existing literature on the topic to date, offering a fresh and deeply enriched view. The originality lies in the capacity to encompass numerous

facets, which are often treated in isolation, to form a structured body of knowledge that is easily navigable for researchers, practitioners, and policymakers grappling with the recent challenges of SPP.

The development of the article unfolds in a methodical sequence, beginning with a literature review, followed by a detailed exposition of the methodology. The article progresses by presenting the results and engages in a discussion that critically examines the implications and nuances of the findings within the context of existing knowledge and practice in SPP. The article culminates with a conclusion that synthesizes the insights gained and offers reflections on the broader impacts of the study.

2 Literature review

According to the World Trade Organization, PP accounts for an average of 10 to 15% of a country's GDP. This underscores the role of the PP process as a strategic tool for fostering sustainable and inclusive growth. Given the pivotal importance of PP in advancing sustainability, it is imperative to delve into the subject of SPP to grasp how it has been approached in scholarly discussions, spot gaps revealing themes and questions that have not yet been sufficiently explored, and ensure the originality and relevance of future work, which is beneficial in avoiding redundancy in studies, and also in enriching the body of knowledge on SPP.

In order to ensure objectivity and rigor in the development of the bibliographic synthesis, the literature review conducted is a systematic literature review (SLR). It differs from the narrative literature review by using systematic, clear, and reproducible [1] methods to identify, select, and critically evaluate relevant research related to a specific research question, as well as to collect and analyse data from the studies included in the review [2]. Given its relevance, the SLR was initially adopted by medical research in the 1970s, before its application was expanded to other academic fields such as management, computer engineering, international development specialties, and supply chain management.

The present SLR is conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. It is a set of guidelines established in 2009 by a team of clinicians, scientific journal editors, systematic literature review specialists, and methodologists, with the aim of helping authors improve the reporting quality of their systematic reviews. It consists of a list of 27 recommendations, spread over four stages as detailed in the flow diagram (Figure 1).

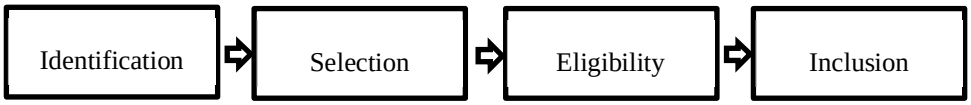

Figure 1 PRISMA flow diagram

3 Methodology

The goal is to establish the state of the art of SPP based on a clear and structured analysis of the available literature, in order to identify the various research axes related to this theme.

3.1 Bibliography identification

Keywords used are « Sustainable public procurement », « Sustainable public purchas* », « government sustainable procurement » and « government sustainable purchas* ». The selected literature sample consists of articles that have undergone peer review, up until February 16, 2023 (the date of collection).

The databases in question are Web of Science and Scopus. The search on these two databases is conducted as follows: (TITLE-ABS-KEY (sustainable AND public AND procurement) OR TITLE-ABS-KEY (sustainable AND public AND purchas*) OR TITLE-ABS-KEY (government AND sustainable AND procurement) OR TITLE-ABS-KEY (government AND sustainable AND purchas*))

After the initial sorting via the bibliographic Management Tool “Zotero”, the selected articles are exported to “NVIVO” (Release 1.7.1) a Qualitative Data Analysis Tool.

3.2 Inclusion and exclusion criteria for literature selection

Excluded are duplicate articles and articles written in languages other than English or French.

Only journal articles are examined. The filter applied during the search is: limit to « Document type (Article), Source type (Journal), Language (English, French). The exclusion will then concern review articles, book chapters, books, book series, conference proceedings, doctoral theses, symposium articles, etc. Articles for which the full text is not available will also be excluded.

The abstracts are read to verify the relevance. Only articles concerning SPP are included. Excluded are the articles deemed irrelevant that deal with the following topics: Personal purchasing behaviours; Sustainable development in a general sense (the areas detected are: transportation, energy management, buildings, sustainable cities, land management, art, culture, education, training, economy, investment, financing, banking sector, social issues, child protection, environmental concerns, access to clean water, food security, access to medical care, rural development, agriculture, aquaculture, fishing, livestock, forest management, mining, tourism, industry, new technologies, management, geopolitics, regulation, waste management); Green Marketing; Private Sector; Territorial Defence; Public-Private Partnership; Humanitarian Supply

Chain; Public finance in general without focusing on the specific case of SPP; Supply chains in general without focusing on the specific case of SPP; Disposal agreements.

The present SLR focuses on articles with an empirical approach (based on surveys, interviews, case studies, multi-method research, and experiments). This choice is based on the fact that the conclusions drawn from these studies are often more reliable and verifiable than those from theoretical research, and are directly applicable to the practice of SPP. The exclusion applies to articles that are based on a conceptual approach (studies focusing on emerging concepts, models, or frameworks, including literature reviews).

3.3 Eligibility

During the meta-analysis phase, the inclusion criteria are applied to the title and abstract. For the in-depth analysis phase, it involves thoroughly reviewing the shortlisted articles to assess their eligibility in the process.

3.4 Inclusion

This final step involves the inclusion of the final articles.

4 Result and discussion

This analysis aims to establish a synthesis of the references (Figure 2).

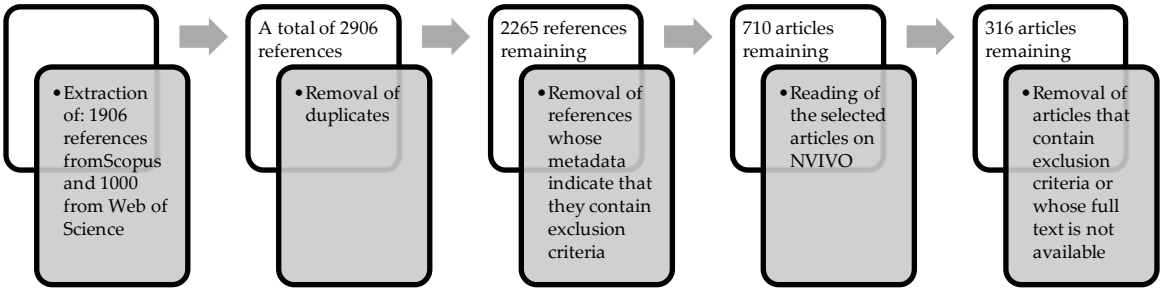

Figure 2 Flowchart of the selection process

The following word cloud (Figure 3) highlights the dominant trends in the text corpus. It is a visual representation of textual data, created using NVivo. It provides an overview of the most frequently used words in a text or a set of texts, thereby drawing attention to the most recurring themes.

Figure 3 Word cloud

To enable in-depth reading from NVIVO, three codes are created: 'Issue', 'Methodology', and 'Result'. A condensed matrix is generated. It consists of a reading sheet that condenses the key information from each of the 316 articles subject to the final selection, in a concise manner. This approach aids in effectively organizing the extensive body of literature. The subsequent sections of the article will detail the most significant findings derived from the analysis of the condensed matrix.

4.1 Descriptive analysis

4.1.1 Geographical distribution

The geographical distribution of empirical research on SPP is diverse and spread across several regions, highlighting the universal importance of the issue (Figure 4). 270 articles concern studies carried out at the national level, with a concentration in certain countries such as the UK (26), Spain (18) and Sweden (18). These articles cover both developed countries (180 articles for 27 countries) and developing ones (90 articles for 29

countries). 42 studies are regional or multinational. 5 articles concern comparative studies between two or a set of countries.

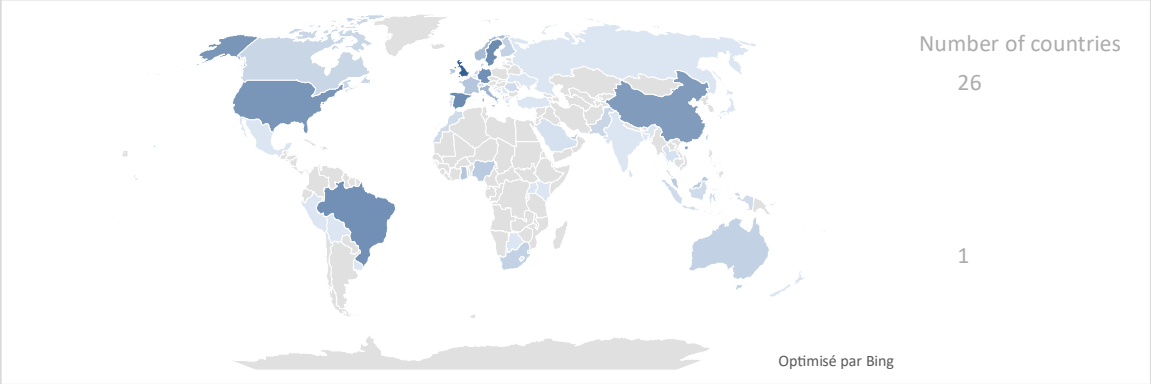

Figure 4 Geographical distribution of empirical research conducted at the national level

4.1.2 Themes and Sub-themes

Structuring the information contained in the reading sheet allows for the identification of 8 main themes. Figure 5 shows the number of articles citing each theme, with an article potentially falling under one or more themes.

Research discussing the barriers and motivations regarding the implementation of SPP dominates with 164 articles, indicating a keen interest in understanding the challenges that prevent certain countries from opting for SPP, as well as the factors that encourage others to embark on this path. Empirical research on e-procurement in the public sector is less common (11 articles).

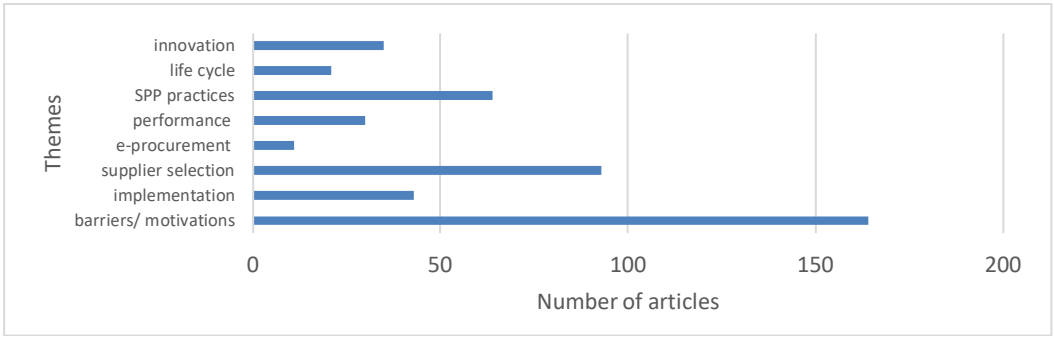

Figure 5 Number of articles per theme

Each of the eight major themes is subdivided into sub-themes as shown in the mind map (Figure 6):

Figure 6 Themes and sub-themes

4.1.3 Chronology

Figure 7 below highlights the evolution of the number of articles on SPP over the years. The trend is upward, indicating a growing interest within the academic community. The literature began to focus on issues related to SPP from the year 2000, when governments started to pay attention to environmental responsibility, following a G7 meeting on the environment in Canada in 1995, during which the various countries developed the concept of 'greening government'; states began to concretely implement actions in response from 2000. The 'Renewed EU Sustainable Development Strategy' introduced on July 16, 2008, is likely the cause of the peak observed in 2009, one of its main objectives being environmental protection. The European Commission's working document 'European Code of Best Practices Facilitating Access for SMEs to PP Contracts' of June 25, 2008, similarly, encourages the use of life cycle cost assessment, the integration of environmental criteria, adherence to social provisions, and the use of sustainable products.

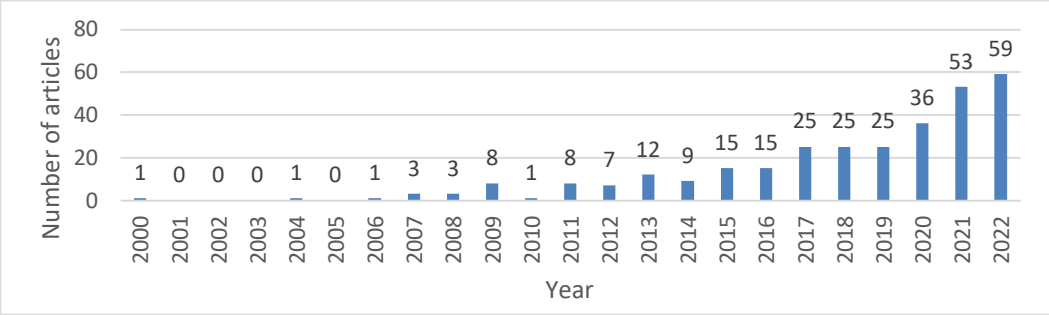

Figure 7 Evolution over the years

Six out of eight sampled articles in 2011 focus on the United Kingdom. This surge in interest can be attributed to several key policy developments. The coalition government, formed in 2010, pledged to foster small business engagement in PP, particularly by aiming to allocate 25% of government contracts to SMEs. The increase in the number of articles in 2015 may be attributed to the implementation of the European 'Directive 2014/24/EU on PP' in 2014. This directive provided national authorities with sufficient flexibility to align procurement processes with social and environmental objectives. This correlation is particularly evident given that, out of the 15 articles in the 2015 literature sample, 13 involve European countries. Empirical articles on SPP have seen a significant increase since 2020. This surge coincides with the development of recovery plans in response to the COVID-19 pandemic crisis, aimed at a sustainable and resilient recovery.

4.1.4 Business sectors

Empirical articles in the field of SPP touch on several specific business sectors, as shown in Table 1. However, with an overall rate of 50%, this table reveals that half of the articles have been published since 2020, indicating growing interest and evolving research in this area across all sectors. With a total of 17 articles and 16 published since 2020, the public administration sector shows a very high rate of recent publication (94%). This suggests a strong focus on SPP in this sector, especially in the recent context.

For the 156 articles published since 2020, we excluded 21 articles submitted before or during March 2020, as they represent a portion of the research that was likely not influenced by the pandemic in their initial conception. Among the remaining 135 articles, 29 explicitly mention the pandemic context of Covid-19. It represents approximately 21.5% of the articles written after the onset of the pandemic. This suggests that the pandemic has had a notable influence on research themes in the field of SPP. It may indicate an increased interest in understanding how sustainable procurement practices can be adapted or have been affected by the unique challenges posed by the pandemic.

Table 1 Articles per sector of activity

Articles per sector of activity (Part ½)			Articles per sector of activity (Part 2/2)		
Sector	Total number of articles	Number since 2020	Sector	Total number of articles	Number since 2020
Acquisition of real estate	**1**	**1**	Urban development	**6**	**3**
Public Administration	**17**	**16**	Transport	**14**	**10**
Food	**38**	**21**	Tourism	**1**	**1**
Furniture	**2**	**1**	Textile	**2**	**0**
Wood	**1**	**0**	Public & private sector	**5**	**0**
Construction	**57**	**28**	Public Sector	**114**	**49**
Infrastructure construction	**10**	**3**	Health	**27**	**11**
Energy	**7**	**4**	Infrastructure	**3**	**2**
Education	**9**	**4**	IT Equipment	**1**	**1**
Health & Education	**1**	**1**	Total	316	156

The sectoral analysis (figure 8) provides an overview of the focus on the pandemic within research on SPP, highlighting the sectors that have been most affected or most responsive in the context of the pandemic. The public sector is the most represented, possibly due to its direct impact on public policies and crisis management. The food sector follows with 6 articles, which may reflect the specific challenges the pandemic has posed in terms of food security, supply chains, and the need for sustainable procurement to ensure food resilience. The health sector is also significant with 4 articles, given that the pandemic has severely tested health systems worldwide.

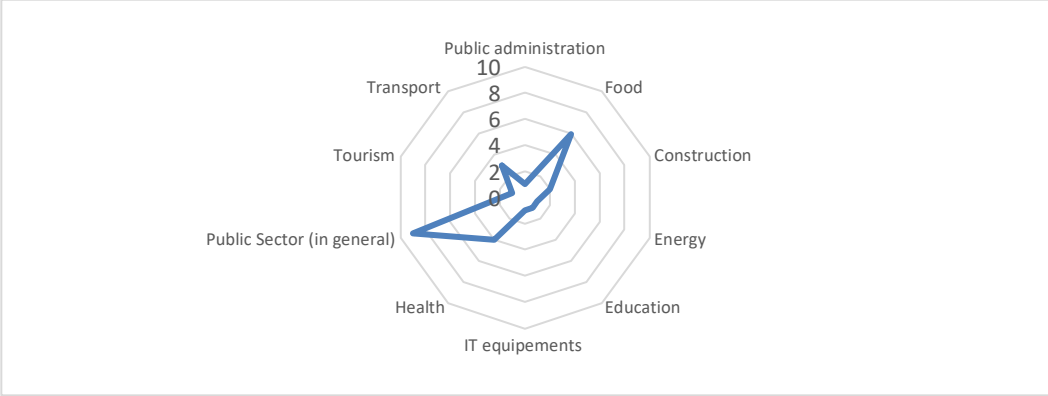

Figure 8 Sectoral analysis of SPP articles where the pandemic context is mentioned

4.2 Thematic analysis

In this section, the themes identified earlier will be explored in depth based on the information provided by the literature sample.

4.2.1 Motivations and Barriers

In the 164 articles addressing the barriers and motivations regarding the adoption of SPP, it was noted that the motivations are either internal or external, and that the barriers can be strategic or operational.

External motivations consist of: 1) Government legislation: This is a primary motivator [3], providing clear standards and criteria for sustainable products and services [4], stimulating eco-friendly market solutions, introducing financial incentives for suppliers offering sustainable products, and imposing restrictions or bans on non-sustainable purchases. Regulations also foster SPP by creating policies that add social value and improve SME access to public markets [5]; 2) Political Commitment: The political leanings of a community, as evidenced by voting patterns, can significantly influence local governments' commitment to SPP, showing a correlation between political preferences and sustainable initiatives [6]; 3) Influence of the Private Sector: Government adoption of SPP signals the private sector to adopt greener practices, encouraging environmental certification and innovation in sustainable solutions, which can lead to a more sustainable economy [7]; 4) Achievement of Sustainable Development Goals (SDG): SPP plays a role in shaping sustainable production and consumption patterns, promoting environmental, social, and economic criteria in procurement processes, and supporting goals like ecological innovation, diversity, and inclusion [8]; 5) Pressure from External Stakeholders: Stakeholders including government agencies, NGOs, international organizations, suppliers, and citizens exert influence on the public sector to implement SPP, varying between developed and developing economies; 6) Economic Recovery: SPP supports economic recovery by favouring local businesses, fostering innovation, creating jobs, and promoting social and economic inclusion of disadvantaged groups, contributing to a sustainable economic recovery.

Internal motivations consist of: 1) Development of local and regional economies: SPP, especially through public food procurement programs, can boost local economies by providing market access to marginalized producers or small-scale farmers [9], supporting local businesses, creating jobs, reducing transportation costs, and enhancing food security [10]. These programs encourage sustainable agricultural practices, contributing to environmental preservation and the long-term health of local communities [11]. SPP also promotes economic growth by offering contract opportunities to local SMEs, fostering innovation, and enhancing the competitiveness of local businesses in broader markets [12]; 2) Cost reduction: Public institutions can lower energy consumption and operational costs by purchasing energy-efficient products and services. Sustainable procurement practices lead to further savings by minimizing waste production and promoting recyclable products, proving to be cost-effective in the long term due to their durability and low environmental impact; 3) Promotion of sustainable consumption: Institutions like universities can encourage sustainable consumption by integrating environmental and social criteria into their procurement processes, thereby prioritizing eco-friendly and ethically sourced products. This involves raising awareness and providing specialized training on SPP [13]; 3) Culture of the public organization: The organizational culture significantly influences the adoption of SPP. The commitment of management to sustainability is crucial. Without it, it can be challenging to secure the necessary resources or create an environment

conducive to SPP practices [14]. A culture that values sustainability, encourages collaboration, and aligns objectives across the public sector is vital for the successful adoption of SPP [15]; 4) Enhancement of the Image: By adopting SPP, public organizations demonstrate their commitment to social and environmental responsibility, which can enhance public trust, prevent corruption, and improve the perception of the organization. Accountability in procurement processes shows that decisions are made ethically and sustainably.

The barriers to SPP represent the factors that can limit its adoption and the effective implementation of its practices. Strategic barriers highlight the fundamental challenges related to the vision and commitment of public organizations: 1) Lack of Support from Top Management: The absence of leadership support for sustainable practices impedes the development of SPP strategies and the encouragement of innovative ideas among employees. Organizational resistance to change, often due to a short-term focus, prevents the uptake of sustainable procurement practices; 2) Inadequate Regulation: A regulatory framework lacking clear sustainability criteria for tenders, or legal clarity on sustainable procurement actions, leaves public buyers wary of considering environmental or social impacts in their purchasing decisions [16]. Additionally, tender processes prioritizing the lowest price over sustainability criteria can result in the acquisition of low-quality products and services [17]; 3) Economic Uncertainties: Budget constraints and the perceived higher costs of sustainable products and services create financial challenges. Although sustainable options may offer long-term savings, a lack of tools and knowledge makes it difficult for public institutions to assess and compare lifecycle costs accurately. Furthermore, strict budget limitations can force a competition between various government priorities and objectives.

Operational Barriers are the obstacles that are more concerned with concrete processes, training, and the availability of tools: 1) Lack of Transparency: identified as a key challenge, as it can lead to public mistrust towards procurement processes, which can compromise the credibility and integrity of PP institutions; because opacity can encourage corruption, favouritism, and fraudulent practices, which can result in the wastage of public resources and the misuse of funds intended for sustainable procurement and the social, economic, and environmental benefits that ensue from it; 2) Complexity of the Procurement Process: Excessive bureaucracy can cause delays, deter suppliers, and complicate the modification of procurement rules. Adopting electronic procurement systems is suggested as a solution to streamline and simplify these processes; 3) Procurement Teams: The lack of training and skills among procurement teams is a significant operational barrier. It's crucial to train public procurement officials in sustainability, ethics, and professionalism, and to promote their moral development. Establishing study groups for standardizing sustainable criteria in tenders and focusing on training that changes attitudes and improves communication can help overcome this barrier [18]; 4) Immaturity of the Supplier Market: A lack of awareness about sustainable products and a limited number of suppliers offering eco-friendly products pose challenges for public buyers aiming to implement sustainability criteria, making it difficult to find suppliers that meet specific sustainability requirements; 5) Lack of Decision Support Tools: The absence of tools can result in an underestimation of environmental costs and decisions made based on economic criteria alone. This barrier also includes challenges such as excessive time spent understanding environmental requirements, a lack of understanding among suppliers of the importance of these requirements, and difficulties in recognizing the value of data collection and life cycle assessment. Guidelines to assist public buyers are essential for reducing the complexities of navigating procurement processes and facilitating the integration of sustainability into procurement decisions [19].

4.2.2 Implementation

The implementation of a SPP process differs depending on the context. Political, organizational, and individual factors can vary from one situation to another, necessitating an approach tailored to each context [20]. Specific actions have been identified to facilitate and enable the implementation of SPP processes, including recognizing the importance of sustainability, legitimizing SPP development work, structuring it, offering expert support for skill development in sustainable procurement, facilitating peer support, introducing environmental requirements in public contracts, setting regulations, collaborating with small producer and conducting regular SPP monitoring.

A procurement strategy is an approach that defines how to achieve the objectives set by the procurement policy, involving the planning and implementation of specific measures to promote sustainable procurement practices. Thus, a SPP strategy involves documenting how to achieve optimal solutions in terms of cost, sustainability, and collaboration when acquiring goods, services, and works, with the aim of achieving environmental, social, and economic objectives in line with national priorities. This strategy also promotes the use of innovative solutions and encourages the creation of value for society, the environment, and the economy in line with the circular economy and sustainable development. Among the most used tools to establish a procurement strategy is the Kraljic model, and also the participatory approach [21].

4.2.3 Supplier selection

PP is conducted through tendering, and the principles of tender award are governed by PP law in each country and can vary depending on the nature of the public contracts and the evaluation criteria used for the tenders. Supplier selection in PP is done using criteria such as the lowest price or the most economically advantageous tender (MEAT). Including environmental criteria in the MEAT

evaluation can be a way to promote environmental sustainability in public contracts. Supplier selection in SPP is based on the application of sustainable criteria, namely the ability to meet specific environmental, social, and economic standards, along with legal compliance. This can be defined in the form of binding technical specifications of the product or service such as the use of recyclable materials, carbon emission reduction, adherence to workers' rights, ..., as requirements for the organization (qualification), in the form of award criteria, or as a performance clause in the contract [22]. Several tools are proposed by the literature to assist public buyers in making more informed and sustainable purchasing decisions in terms of supplier selection and PP awarding.

4.2.4 e-procurement

The implementation of an electronic PP system presents several potential advantages, including: the reduction of time and effort required to complete procedures through the automation of procurement processes, complete traceability of the flow of information and materials, enhancing transparency and integrity, reduction of costs related to procurement procedures, such as printing, storage, and distribution of physical documents, equitable access to all interested parties, eliminating geographical barriers and allowing wider participation, simplification of administrative tasks, speed and efficiency of communication between stakeholders and reduce human errors [23], thus accelerating the procurement process, strengthening compliance with established rules and regulations, reducing the risks of misconduct, and securing data, which facilitates the detection of irregularities and fraud.

Digital transformation facilitates the transition towards sustainability of SMEs, given the advantages offered in terms of transparency through better traceability of transactions which facilitates the detection of fraudulent behaviour, optimization of resources, better collaboration between private and public sector actors, which can encourage innovation in terms of sustainability and access to new markets [24].

The main organizational challenges that can compromise the success of the adoption of the electronic PP system are resistance to change from some process actors, technical complexity requiring skills and adequate infrastructure, protection of sensitive and confidential data requiring robust security measures to prevent breaches and cyberattacks, and inequality of access since the actors involved in PP may not have equitable access to the necessary technological resources, which can create disparities and inequalities in the procurement process [25].

The impact of blockchain technology and the Internet of Things (BIoT) on PP has been examined. The results show that blockchain technology can be used at all stages of the PP process. For example, it can be used to improve the efficiency of inventory management, eliminate malicious submissions, and enhance transaction transparency. Blockchain also allows for the secure and transparent tracking of the use of public funds and ensures the traceability of processes. This contributes to reducing corruption and making government services more transparent and efficient. By combining blockchain technology with the IoT, it is possible to create an intelligent and interoperable PP ecosystem [26]. Da Silveira et al. highlight that by enabling the tracking of the entire supply chain, blockchain facilitates the verification of sustainability criteria required in the tendering process. This helps to detect environmental and social damages such as the use of child or forced labour, the use of wood from deforestation, counterfeit products, unethical agents, etc. Moreover, by providing more transparency to the acquisition process, blockchain promotes open innovation by allowing stakeholders to collaborate and share information confidently. This can encourage public actors to adopt sustainable purchasing practices and to promote innovative solutions to achieve their sustainability goals.

4.2.5 Performance

Performance evaluation occurs at an early stage of the procurement process, during the planning and design of the project, and before the tendering process is initiated. It can also be conducted during the process or at a later stage, where the sustainability assessment of a procurement strategy is established to measure how well this strategy meets the SDGs, thus identifying areas where improvements can be made to make the strategy more sustainable and aligned with sustainable development priorities [27].

Performance indicators provide an objective basis for making informed procurement decisions and encourage more responsible practices [28].

4.2.6 SPP Practices

The selected literature sample mentions several environmental practices to promote SPP. Among these are practices aimed at fostering the transition to more sustainable mobility and reducing CO2 emissions, through the introduction of environmental procurement policies, the establishment of a reverse logistics system for the backward flow of products to prevent pollution and reduce waste generation, the implementation of sustainability criteria in tender processes, considering psychological, cultural, and infrastructural factors, and encouraging functional specifications rather than specific prescriptions of solutions or materials, to foster innovation and ensure that suppliers offer environmentally friendly products and services in the market [29].

Social practices within the framework of SPP include the inclusion of minority-owned businesses or marginalized groups [30] in public sector set-aside programs by allocating a portion of procurement expenditures to them while encouraging the economic development of these groups, the development of projects that create new opportunities for local communities, the creation of employment opportunities and the promotion of

economic empowerment of disadvantaged populations through subcontracting and purchasing from businesses of all sizes.

The economic benefits of SPP include long-term savings from more efficient resource use, the stimulation of innovation, the creation of markets for sustainable products, and also regional economic development and building community wealth [31].

4.2.7 Life cycle

Life cycle assessment (LCA) is used as a key tool to assess environmental impacts and costs, thereby facilitating the choice of more efficient solutions [32]. Life cycle cost (LCC)is an economic evaluation method that considers all costs associated with the acquisition, operation, maintenance, and disposal of a product or system over its life cycle. Both evaluations (LCA and LCC) are considered complementary, as the first helps to identify and minimize negative environmental impacts, while the second allows understanding and managing the long-term economic implications. The integration of these two analyses in procurement and design processes aims to promote more sustainable and economically viable decisions.

4.2.8 Innovation

Innovation can concern both the purchased product or service and the procurement process itself. Indeed, public demand for solutions contributing to the achievement of objectives can be a powerful driver of innovation and facilitate the development of sustainable products and services. However, innovation encounters numerous obstacles such as the difficulty in making innovations repeatable and sustainable over time, especially in the public sector where procurement regulation is often rigid and aims to ensure open and fair competition, resistance to change and leadership styles [33].

In terms of the procurement process, innovation is crucial for developing frameworks for innovative procurement [34]. The shift from traditional contracts to integrated contracts, for example, leads to fundamental changes in the interdependencies among actors, resources, and activities, which can influence innovation and sustainable development. Smart contracts using Blockchain is also presented as a key technological innovation to overcome barriers to sustainability in SPP, by offering reliable traceability, improving transparency and efficiency, and helping to prevent fraud [35].

5 Conclusions

The results reveal that SPP is gaining popularity due to its potential to foster responsible economic growth and sustainable development. The SLR highlights a trend towards geographical diversification, affirming the global importance of the subject. However, a difference is observed between developed and developing countries in terms of adopting SPP. In developed economies, coercive pressures are often stronger and take the form of government regulations, green procurement policies, and specific customer requirements for sustainability; they generally have greater awareness and citizen pressure in favour of sustainability, which can lead to a faster adoption of SPP. NGOs and local media also play an important role in raising awareness of sustainability issues. In contrast, in developing economies, coercive measures are often less binding, and SPP is more often considered a voluntary requirement. Some developing economies have implemented initiatives to promote SPP, but they may face legal and operational challenges, which can make the adoption of SPP more difficult, as legal pressures alone are weak due to the absence of sanctions for non-compliance.

Since the onset of the COVID-19 pandemic in 2020, there has been a substantial surge in the volume of scholarly articles, covering the field of SPP. These publications emphasize the need for emergency preparedness, underlining how the crisis has laid bare the fragility of healthcare systems and public finances.

The pandemic has acted as a catalyst for green recovery initiatives, shifting focus towards sustainable development. It has disrupted urban food systems globally, revealing the weak points in ensuring nutritional security for the more vulnerable city dwellers, which proves the importance of resilient local food systems. This shift not only aids in pandemic recovery but also aligns with broader sustainability goals by reducing carbon footprints and fostering community resilience. Additionally, the pandemic unveiled the disproportionate effects on SMEs at large, with a pronounced impact on women-led SMEs, minority-owned enterprises, and marginalized groups, catalysing governmental social innovations in PP that generate value.

Delays in project deliveries were commonplace due to disruptions in supply chains. Furthermore, there has been a noticeable acceleration in the adoption of teleworking as governments have sought to maintain service continuity; this has led to increased IT expenditures. The urgency to expand telehealth services has led to substantial investment in infrastructure and policy adaptation.

The pandemic has accelerated the adoption of digital technologies in PP, notably e-procurement and blockchain. However, the full potential of these technologies in the realm of SPP remains largely untapped and the lack of empirical articles in this regard highlights a neglected research area. This deficiency underscores a critical need for exploration on how blockchain can improve traceability, transparency, and efficiency in PP while respecting sustainability principles. The role of IoT in SPP represents another area of digital transformation. However, there is a glaring lack of empirical articles examining the concrete impact and practical applications of BIoT in PP. These combined technologies have the potential to revolutionize PP by enabling better real-time tracking, cost reduction, and increased efficiency in procurement processes.

It is equally important to note that artificial intelligence (AI) is absent from most research on SPP, a surprising

finding given the extent of its promises. By analysing large amounts of data and identifying complex trends, AI could optimize procurement processes, promote informed and personalized decision-making, and contribute to better risk management. The introduction of AI could thus transform PP, making it more agile and strategic. This gap underscores an urgent need for empirical analyses to explore the implications, benefits, and potential constraints of using AI in optimizing SPP. There is also a lack of empirical articles focused on analysing the risks associated with data security in the digitalization of PP. The existing literature offers little insight into concrete vulnerabilities and security incidents that have occurred in the context of electronic PP processes.

This research highlights that while there is a focus on evaluating environmental impacts using LCA and LCC in PP practices, there's a notable scarcity in addressing social life cycle analysis. This gap hinders a comprehensive understanding of the social implications of PP decisions and limits the ability of organizations to make informed, responsible choices. Additionally, the SLR observes a strong inclination towards prioritizing environmental criteria over social ones in supplier selection. The difficulty in addressing social aspects could be attributed to their qualitative, subjective nature and the challenges in quantifying them similarly to environmental impacts. This imbalance underscores the necessity for research to incorporate social criteria more thoroughly, aligning PP with broader socio-economic values alongside environmental considerations to achieve comprehensive sustainability goals.

The implementation of SPP principles through effective and optimized processes is also not sufficiently documented. This gap in research can be explained by the fact that the methodology for implementing SPP can vary considerably depending on regulatory, cultural, and economic contexts, complicating the creation of a uniform analysis framework or the adoption of a standardized approach. It is therefore essential to enrich the academic corpus and provide case studies, models, and practical tools that could guide and facilitate the implementation of SPP within public administrations. In the context of the study conducted, there is also a lack of articles dealing with the formulation of procurement strategies, which is an important element of a responsible and efficient procurement approach. Moreover, this SLR exposes a lack of papers dedicated to evaluating the sustainability of procurement strategies, making it difficult to measure their effectiveness, assess whether the expected impact on the environment, society, and economy is achieved, and make improvements based on evidence.

It is important to draw attention to a notable limitation of this SLR, which lies in the choice to include exclusively empirical articles. This restriction has probably contributed to the limited number of articles identified concerning innovation in SPP, as researchers often orient themselves in emerging fields towards theoretical or conceptual approaches to explore and establish foundations before conducting empirical studies. Not to mention the fact that this type of study requires concrete data, often in the form of case studies, experiences, or data collected in the field, which can take longer to be published due to challenges related to data access, regulatory constraints, and coordination between different stakeholders; therefore, studies may be underway but not yet published.

In conclusion, the insights garnered from this review highlight the evolving nature of SPP in ensuring the resilience and sustainability of supply chains, especially in the face of global crises like COVID-19. The pandemic has not only challenged existing practices but also opened new pathways for innovation in PP. As the world continues to grapple with the pandemic's aftermath and other global challenges, SPP stands as a pivotal mechanism in steering societies towards a more sustainable, resilient, and equitable future.

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Supply chain risk assessment using best worst method: a case study of agro-industry skipjack tuna in Ambon - Indonesia
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Abstract: One of the main issues in the agro-industry supply chain is identifying and ranking different risk factors to maintain business continuity. This study discusses the agro-food supply chain risk assessment for smoked skipjack tuna in Ambon. Related literature and expert interviews identify risk factors that arise along the supply chain. These risk factors are contained in internal risk, company external operational risk, and macro-level risk. This research aims to evaluate comprehensively the risk factors of the smoked skipjack agro-industry supply chain, which are a priority to be addressed. The decision-making framework uses the BWM (Best Worst Method) to determine each risk factor's relative weight, followed by a sensitivity analysis to determine how robust the outcome is. Experts pick the risk factor assessment, and then an optimization model is modelled to obtain the weight of each risk factor, which is calculated with the help of Lingo software. The findings show that three risk factors will be prioritized to be addressed out of the eleven risk factors assessed, namely "Quality of the final product," "Financial instability," and "degradation of fish populations." Sensitivity analysis was also carried out to see the overall robustness of the results achieved. The weight of the selected risk factor ("final product quality (R1c)") has its weight value changed from 0.1 to 0.9 with an increase of 0.1. These findings are expected to help smoked skipjack tuna agro-industry managers make decisions to reduce supply chain risks and better administration management to maintain the sustainability of their business processes.

1 Introduction

One of Indonesia's fishery commodities with quite promising market potential is skipjack tuna (Katsuwonus pelamis). Tuna and skipjack tuna fishery commodities can be exported as fresh, frozen, processed products such as smoked skipjack [1]. Smoked skipjack tuna is one of the products processed using a combination of treatment and the administration of natural chemical compounds from burning natural fuel. Currently, the skipjack tuna supply chain in the eastern region is the same as in Ambon, mainly consisting of fishermen - large traders or Fish Management Units - small traders - processors, and then consumers [2]. Even though it is a mainstay commodity, the skipjack fishery supply chain faces risks to business sustainability, such as varying quality, post-catch handling processes and handling during loading and unloading, and the use of ice for cooling, which will have an impact on the quality of the smoked fish to be produced.

In a business environment that involves many actors in the supply chain, different situations in both the time and place dimensions will create a situation of uncertainty, thereby creating risk agents. Risk can be defined as the possibility of losses arising or unexpected events due to uncertain conditions resulting in losses for the company [3,4]. Risk cannot be avoided, but its overall impact can be minimized with appropriate risk management through risk identification, evaluation, and mitigation to ensure the smooth running of the company's business processes [5]. [6] define risk identification as a systematic process for identifying and categorizing risks and the causes of risk. According to [7], Supply Chain Risk Management (SCRM) also includes risk identification and evaluation, which aims to reduce supply chain operational disruptions and their negative impacts. Risk evaluation is the stage of risk measurement and assessment that aims to assist the decision-making process in preventing risk [8].

According to [9], research on Supply Chain Risk Assessment (SCRA) for the agri-food context still needs to be improved compared to SCRA research for other contexts, such as the manufacturing sector. Several studies on Agro-food Supply Chain Risk Assessment (AFSCRA) have been carried out using several multi-criteria decision-making (MCDM) methods, including Rathore et al. [10] uses the Failure Mode and Effect Analysis (FMEA) method combined with fuzzy VIšekriterijumsko KOmpromisno Rangiranje (fuzzy-VIKOR) to determine supply chain risk priorities in the foodgrains industry. The FMEA method was also used by [11] which is integrated with fuzzy Technique for Order Preference by Similarity to Ideal Solution (fuzzy-TOPSIS) and fuzzy Analytical Hierarchy Process (fuzzy-AHP) in identifying and classifying supply chain risks in agricultural projects. Likewise Suryaningrat et al. [12] used FMEA and AHP in determining the risk weight of edamame commodities in the agricultural industry. Furthermore, [13] use a fuzzy House of Risk (FHoR) approach in identifying and mitigating agro-industrial sugarcane risks to improve supply chain performance. The AHP based on spherical fuzzy sets (SF-AHP) approach was used by [14] in investigating the impact of risks on agricultural supply chains after COVID-19.

However, to the best of our knowledge, a comprehensive review of AFSCRA research for fishery products is still very rarely carried out when compared to Horticultural products and general food and other food products classified by [15]. Several AFSCRA studies for fishery products have been carried out by [16] in assessing supply chain risks for mackerels by conducting simulations using the Colored Petri-Net (CPN) method. Furthermore, [17] carried out risk identification, assessment, and mitigation in the tuna industry in three dimensions of sustainability using the HoR method. Likewise, [18] studied the identification and assessment of risks in the operational aspect of the supply chain in the canned tuna industry using the FMEA and VIKOR methods. The current research uses the best worst method (BWM), one of the MCDM methods developed by [19], by identifying risks and assessing the supply chain risks of smoked skipjack tuna in Ambon. Therefore, this research provides novelty by contributing to the AFSCRA literature by identifying risk factors in three aspects, namely macro-level risk, operational risk external to the firm, and internal risk, as well as assessing risk factors related to offering BWM, especially the Skipjack tuna supply chain.

Based on the explanation above, the formulation of the problem presented in this study is how to identify and assess risk factors for the smoked skipjack supply chain and how priority risk factors help provide practical insights for company managers. By realizing the importance of SCRM, the firm can arrange, execute, and manage the SCM process to maintain the SC and the sustainability of the smoked skipjack agro-industry. This research aims to identify risk and evaluate the risks of the smoked skipjack tuna SC using BWM.

2 Research methodology

The methodical processes taken to accomplish the intended aims are known as research methodology. This study examines the identification and risk evaluation in Ambon's supply chain for smoked skipjack tuna. This research has gone through several stages, including:

Stage 1. *Identify initial supply chain mapping.* At this stage, an initial mapping of the smoked skipjack tuna supply chain was done through interviews and previous research literature studies.

Stage 2. *Identify potential risk factors.* At this stage, risk factors are identified in three categories, namely macro-level risk (MR), operational risk external to the firm (OR), and internal risk (IR), which were adapted from [5]. The identification process was taken out through literature studies and deep discussions with experts (marine and fisheries office of Ambon, industry and trade office of Ambon, academics, smoked fish agro-industry groups, and fishermen groups) and validated to obtain risk factors (Table 1), which will then be used in preparing a paired comparison assessment questionnaire with a scale from 1 to 9 as input to the BWM model.

Table 1 Risk factors in the smoked skipjack tuna supply chain

Categories	Risk Factor, Codes and Reference	Definitions
Internal Risk	Lack of skilled workers (R1a) [18]	Agroindustry faces a shortage of skilled workers.
	Financial instability (R1b) [20]	Circumstances that describe the company's financial condition in an unstable condition
	Final product quality (R1c) [17,18]	Decrease in final product quality that does not comply with Indonesian National Standard 2725:2013, namely > 60%, histamine levels > 100 mg/100g
Operasional Risk	Demand uncertainty (R2a) [21]	Uncertainty in demand that causes demand to suddenly increase or decrease
	Supply quality (R2b) [4,20]	Quality of raw materials supplied from suppliers
	Supplier delivery delays (R2c) [5]	Not being able to deliver raw materials on time causes many problems

Macro Level Risk	Regulations and policies (R3a) [22]	Unsupportive regulations and policies, for example, regulations limiting operational hours for catching during a pandemic, managing fishing permits, increasing fuel prices.
	Conflicts between fisherman groups/agro-industry groups (R3b) [17]	Conflict between members of society that is comprehensive in life
	Fish population degradation (R3c) [23]	Reduction in fish populations as a result of overfishing
	Damage and contamination (R3d) [18]	Product damage and contamination during production and transportation
	Natural disasters (R3e) [5]	Potential losses caused by natural disasters such as bad weather, power outages

Stage 3. BWM Application. In this phase, risk factors are assessed by experts through a questionnaire and will be ranked by calculating the average optimal weight for each risk factor resulting from BWM. Dr. Jafar Rezaei developed BWM in 2015, a relatively new MCDM technique. BWM uses two pairwise comparison vectors in determining the weight of criteria; the first is the one that is "best," the most important or most desirable of the other criteria, and the second is the "worst," such as the least desirable or least necessary of the other criteria [19]. BWM consists of several steps, namely:

i. **Set of relevant risk factors.** In this phase, risk factors are identified from the aspects of and macro-level risk (MR), operational risk external to the firm (OR), internal risk (IR), which experts then validate, and there are eleven relevant risk factors (see Table 1)

ii. **Selected the best and the worst risk factors.** The expert will select the "best" risk factor and the "worst" risk factor from the risk factors that have been identified. It can be decided randomly whether the risk factor is the best or worse if there is a tie. The decision-maker's judgment is wholly responsible for this.

iii. ***Determine the preference of the best risk factor over all the other risk factors***. In this phase, a pairwise comparison assessment is carried out between the "best" risk factor (*B*) and other factors ($j = 1,2,...,n$). Then created in a row vector as in equation (1).

$$A_B=(a_{B1},a_{B2},...,a_{Bn}) \quad (1)$$

Where a_{Bj} shows the best preference for risk factor *B* compared to risk factor *j*.

iv. *Determine the preference of all the risk factor over the worst risk factors*. In this phase, a pairwise comparison assessment is carried out between the "worst" risk factor (*W*) and other factors ($j = 1,2,...,n$). Then created in a column vector as in equation (2).

$$A_W=\begin{pmatrix} a_{1W} \\ a_{2W} \\ ... \\ a_{nW} \end{pmatrix} \quad (2)$$

Where a_{jw} shows the level of preference for the worst risk factor *W* compared to risk factor *j*.

v. *Modeling the optimization model and calculating the optimal weight of each risk factor.* This stage will create an optimization model to calculate each risk factor's weight, represented in equation (3). The calculation of the weight of apiece risk factor using Lingo software. The formulation to find the optimal weight is modeled as follows:

$$min\ max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_B}{w_j} - a_{Bj} \right| \right\} \quad (3)$$

Subject to,

$\sum_J w_j = 1$

$W_j \geq 0,$ for all j

Then converted into a linear model as follows (4):

$$min\ \xi^L \quad (4)$$

Subject to,

$\left| W_B - a_{Bj} w_j \right| \leq \xi^L,$ for all j

$\sum_J w_j = 1$

$W_j \geq 0,$ for all j

3 Result and discussion

3.1 Smoked skipjack tuna supply chain

The fish supply chain in Ambon starts with fishermen who catch skipjack tuna. The number of skipjack tuna caught by fishermen ranges from 250-1000 in one go to sea. Furthermore, the skipjack tuna is sold to collectors or wholesalers, and some are also sold to the Fish Management Unit (UPI) / cold storage to be used as frozen products. After the fish is distributed to collecting traders, the fish is then sold directly to consumers or to agro-industry to be made into smoked fish. Fish that will be used as smoked fish products are processed by smoking (3-4 hours) using hardwood or coconut shells to maintain the quality of the product. Next, the smoked fish is directly distributed to retailers to be sold to consumers and processed into other food products. In general, the smoked skipjack tuna supply chain is shown in Figure 1.

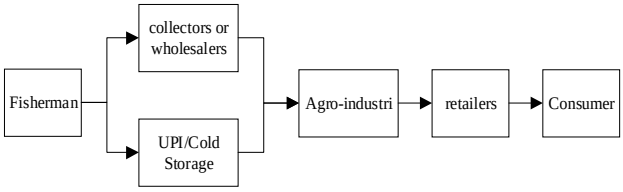

Figure 1 Smoked skipjack tuna supply chain

3.2 Best worst method application

BWM will be used to assess risk factors identified from various literature and verified by experts. The results of expert identification and verification through literature studies and interviews can be seen in Table 1.

Selected the best and worst risk factors

In this phase, five experts determine the "best" and "worst" risk variables once given a set of pertinent risk factors. Experts were drawn from the provincial fisheries and maritime service, city industry service, academics, smoked fish agro-industry group, and fishermen group, based on years of involvement and work experience. Interviews were conducted with experts directly to assess risk factors on the questionnaire that had been designed. The selection of the “best” and “worst” risk factors from the five experts is shown in Table 2.

Table 2 The best and worst risk factors determined by experts

Risk factors	Best risk factor	Worst risk factor
Lack of skilled workers (R1a)	Expert 1	
Financial instability (R1b)		
Final product quality (R1c)	Expert 2, 4, and 5	
Demand uncertainty (R2a)		
Quality of supply (R2b)		
Supplier delivery delays (R2c)		
Regulations and policies (R3a)	Expert 3	
Conflict between fishermen/agro-industry groups (R3b)		Expert 4 and 5
Degradation of fish populations (R3c)		Expert 2 and 3
Damage and contamination (R3d)		
Natural disasters (R3e)		Expert 1

Determine the preference of the best risk factor over all the other risk factors

In this phase, by using pairwise comparisons on a 1–9 rating scale, the five experts were asked to rate their propensities for the best risk factor that had been chosen relative to the other risk factors. Table 3 illustrates how Expert 4 chose the best risk factor compared to other risk factors.

Table 3 Best risk factor in comparison to other risks (expert 4)

Best to others		R1a	R1b	R1c	R2a	R2b	R2c	R3a	R3b	R3c	R3d	R3e
Expert 4	Best risk factor (R1c)	7	5	1	7	7	9	5	9	3	5	5

Determine the preference of all the risk factor over the worst risk factors

In this stage, using pairwise comparisons and a rating scale from 1 to 9, five experts were asked to rate their judgment of their propensity for other risk factors about the worst risk factors. Table 4 is an illustration of a matrix that Expert 4 evaluated.

Table 4 Worst risk factors compared to other risk factors (expert 4)

Others to worst	Expert 4 (Worst risk factor R3b)
Lack of skilled workers (R1a)	3
Financial instability (R1b)	3
Final product quality (R1c)	9
Demand uncertainty (R2a)	5
Quality of supply (R2b)	7
Supplier delivery delays (R2c)	7
Regulations and policies (R3a)	5
Conflict between fishermen/agro-industry groups (R3b)	1
Degradation of fish populations (R3c)	1/3
Damage and contamination (R3d)	5
Natural disasters (R3e)	7

Modeling the optimization model and find the optimal weight

By completing the optimization model and the restrictions in Equation 4, this phase finds the ideal weight for each risk factor. The following describes the optimization model for Expert 4:

$$
\begin{aligned}
&\min \xi^{L} \\
&\text{Subject to,} \\
&|w_{R1c}-7w_{R1a}| \le \xi^{L};|w_{R1c}-5w_{R1b}| \le \xi^{L};|w_{R1c}-1w_{R1c}| \le \xi^{L};|w_{R1c}-7w_{R2a}| \le \xi^{L}; \\
&|w_{R1c}-7w_{R2b}| \le \xi^{L};|w_{R1c}-9w_{R2c}| \le \xi^{L};|w_{R1c}-5w_{R3a}| \le \xi^{L};|w_{R1c}-9w_{R3b}| \le \xi^{L}; \\
&|w_{R1c}-3w_{R3c}| \le \xi^{L};|w_{R1c}-5w_{R3d}| \le \xi^{L};|w_{R1c}-5w_{R3d}| \le \xi^{L}; \\
&\quad |w_{R1a}-3w_{R3b}| \le \xi^{L};|w_{R1b}-3w_{R3b}| \le \xi^{L};|w_{R1c}-9w_{R3b}| \le \xi^{L};|w_{R2a}-5w_{R3b}| \le \xi^{L}; \\
&|w_{R2b}-7w_{R3b}| \le \xi^{L};|w_{R2c}-7w_{R3b}| \le \xi^{L};|w_{R3a}-5w_{R3b}| \le \xi^{L};|w_{R3b}-1w_{R3b}| \le \xi^{L}; \\
&|w_{R3c}-0.33w_{R3b}| \le \xi^{L};|w_{R3d}-5w_{R3b}| \le \xi^{L};|w_{R3e}-7w_{R3b}| \le \xi^{L}; \\
&w_{R1a}+w_{R1b}+w_{R1c}+w_{R2a}+w_{R2b}+w_{R2c}+w_{R3a}+w_{R3b}+w_{R3c}+w_{R3d}+w_{R3d} = 1 \\
&w_{R1a},w_{R1b},w_{R1c},w_{R2a},w_{R2b},w_{R2c},w_{R3a},w_{R3b},w_{R3c},w_{R3d},\ w_{R3d} \ge 0
\end{aligned}
\tag{5}
$$

Other mathematical models for experts 1,2,3, and 5 are carried out the same way for expert 4. This optimization model is completed with the help of Lingo software. The data processing results with Lingo software obtained optimal weights for each relevant risk factor from experts 1,2,3, 4, and 5 and are shown in Table 5. Additionally, as stated by [19], the value of ξ^{L*} for this model may be directly regarded as an indication of the consistency ratio of pairwise comparisons, with a value of ξ^{L*} near to zero denoting a high level of consistency. The value of ξ^{L*} is close to zero based on the output results, so the consistency of the pairwise comparisons is reliable.

Table 5 Optimal weight for each risk factor

Risks Factors	Optimal weights (w_j*)				
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
R1a	0.118	0.046	0.038	0.057	0.037
R1b	0.193	0.107	0.132	0.080	0.112
R1c	0.028	0.322	0.029	0.330	0.336
R2a	0.064	0.046	0.029	0.057	0.048
R2b	0.096	0.064	0.132	0.057	0.067
R2c	0.064	0.036	0.029	0.045	0.048
R3a	0.048	0.064	0.264	0.080	0.067
R3b	0.048	0.036	0.038	0.045	0.037
R3c	0.219	0.107	0.088	0.086	0.067
R3d	0.096	0.064	0.088	0.080	0.067
R3e	0.024	0.107	0.132	0.080	0.112
ξ^{L*}	0.075	0.000	0.000	0.071	0.000

The simple average of the optimal weights produced by the model for the five experts is computed to provide the final results. Table 6 and Figure 2 show each risk factor's ultimate ideal weight and ranking.

Table 6 Optimal weight for each risk factor

Risk Factor	Average weight (w_j*)	Average ξ^{L*}	Ranking
R1a	0.059	0.029	8
R1b	0.125		2
R1c	0.209		1
R2a	0.049		9
R2b	0.084		6
R2c	0.044		10
R3a	0.105		4
R3b	0.041		11
R3c	0.114		3
R3d	0.079		7
R3e	0.091		5

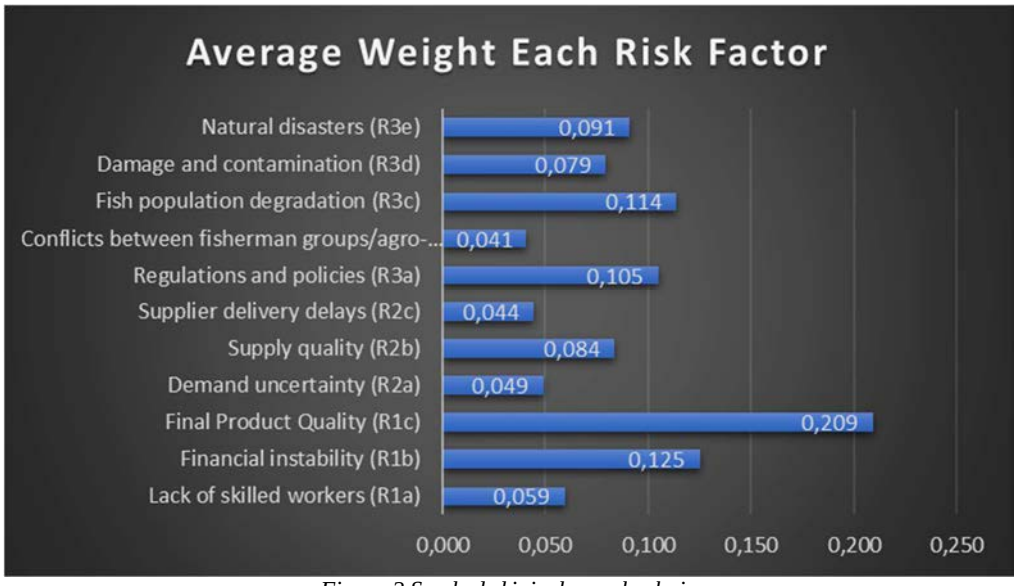

Figure 2 Smoked skipjack supply chain

The research results show that "final product quality (R1c)" is the most critical risk factor for the smoked skipjack tuna supply chain with the highest weight, 0,209. This is also reinforced by several previous studies, such as those conducted by [4,17,18] which show that the most significant risk from fish agro-industry is a decrease in the quality of the final product. The risk of "final product quality" shows that the quality management system may not function properly from upstream to downstream; this will impact business performance and pose a risk of losing consumers. Rasulu et al. (2020) state that one of the critical points of the skipjack tuna agro-industry lies in post-catch handling because it has a product that is easily damaged and contaminated with microbes. Apart from that, several factors can increase the risk of decreasing the quality of smoked skipjack tuna, including: 1) Unhygienic processing: If the fish is not processed correctly and does not meet high sanitation standards, then there is the potential for contamination by bacteria, germs or dangerous chemicals. This can hurt the quality of the fish and the risk of causing disease if consumed; 2) Lack of cooling process temperature: the cooling center temperature must be maintained between 0-4.4^0 C to prevent bacterial growth and histamine formation [25]; 3). Poor quality raw materials: The quality of skipjack tuna used as raw material also affects the quality of smoked skipjack tuna. If the fish used is not fresh or has problems, then the quality of the processed fish will also be affected; 4). Production process that does not meet standards: If the smoked skipjack tuna production process is not carried out properly or does not comply with established standards, the quality of the fish can decrease.

The following risk factor is "Financial instability (R1b)," which comes in second place with a weight of 0.125 in the final analysis. This risk element needs to be treated carefully for the smoked skipjack agro-industry in Ambon City to operate sustainably. Financial instability is an essential factor for the sustainability of business organizations because financial instability can affect the performance of business activities [20]. Smoked skipjack fish agro-industry players in Ambon City have a small capital to run their business, so sometimes the fish purchased from collectors will be paid after the product is sold out, so agro-industry development becomes difficult due to limited capital. For this reason, the government/stakeholders need a critical role in providing opportunities for agro-industry to develop [26] such as reducing burdensome regulations, helping to facilitate cooperation with financial institutions through business education, and encouraging subcontracting activities.

The third most significant risk factor, weighting 0.114, for the supply chain of smoked skipjack tuna is "fish population degradation (R3c)". This is a significant risk factor because it will impact the number of catches of skipjack tuna, which will simultaneously affect the amount of smoked skipjack tuna production. [27,28] stated that overfishing is one of the leading causes of fish population degradation. Many fishermen engage in irresponsible fishing (overfishing), such as using fishing gear that damages the marine ecosystem or catching fish still in their spawning period. As a result, the number of skipjack tuna has decreased drastically. In addition, habitat destruction also plays a role in the degradation of skipjack tuna populations. Destruction of coral reefs, mangroves, and other coastal ecosystems results in losing places to live and food sources for skipjack tuna. The degradation of skipjack tuna populations has a broad negative impact on the supply chain of smoked skipjack tuna agro-industry. Therefore, to overcome the degradation of the skipjack tuna population, the government has issued a measurable fishing policy and

habitat preservation. Apart from that, collaboration between the government, fishermen, agro-industry entrepreneurs, and the community must also be engaged for the skipjack agro-industry SC to be sustainable.

According to this study, the fourth significant risk factor, with a weight of 0.105, was "regulation and policy (R3a)". This risk factor may be a key risk factor for the smoked skipjack tuna agro-industry supply chain, as evidenced by regulations restricting fishing hours during the pandemic [4] and policies raising fuel prices [29], which have an impact on the high operational costs for fishermen in fishing. For this reason, the government, as a policymaker, needs to formulate a policy that can provide a win-win solution for all parties in the skipjack tuna supply chain.

In addition, the risk factors for “natural disasters (R3e)”, “quality of supply (R2b)”, and “damage and contamination (R3d)” are ranked fifth, sixth, and seventh with respective weights of 0.091, 0.084, and 0.079. [5], The risk factor for natural disasters is the potential loss caused by natural disasters such as bad weather as a result of the current El Nino storm, blackout of the supply of electrical energy, which affects the power source for cold storage for skipjack tuna storage. The risk factor for the quality of skipjack tuna supply for agro-industry also significantly impacts the quality of the smoked skipjack produced. The risk factor for damage and contamination is also a significant risk factor for the smoked skipjack supply chain, which requires that the final product produced be in accordance with the quality of the Indonesian National Standardization.

Finally, the risk factors "Lack of skilled workers (R1a)", "Uncertainty of demand (R2a)", "Delays in supplier deliveries (R2c)", and "Conflict between fishermen/agro-industry groups (R3b)" occupy the eighth, ninth, tenth positions. And eleventh, with their respective weights tending to be the same, namely 0.059, 0.049, 0.044, and 0.041. The lack of skilled workers can also affect the final product produced, so work experience is needed from workers. Delays in deliveries from suppliers also hurt the smoked skipjack tuna supply chain, which will further reduce the performance of the smoked skipjack tuna agro-industry. Therefore, it is necessary to look for several suppliers as suppliers of raw materials for the smoked skipjack tuna agro-industry to maintain the production process. Furthermore, conflicts between fishermen/agro-industry need to be handled by building harmonious and dynamic social interactions in building relationships through communication with the formation of fishermen or agro-industry groups [17].

3.3 Sensitivity analysis

A sensitivity analysis was performed in this study to evaluate the general robustness of the results. The risk factor with the most significant weight value in this sensitivity analysis had its weight adjusted from 0.1 to 0.9 [30,31]. Table 7 below shows the outcomes of changing the weight of the "quality of the final product (R1c)" risk factor sensitivity analysis from 0.1 to 0.9:

Table 7 Weight of each risk factor during sensitivity analysis

Risks Factors	Risk factor preference weight values									
	0.1	**0.2**	**Normal (0.209)**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
R1a	0.068	0.060	0.059	0.053	0.045	0.038	0.030	0.023	0.015	0.008
R1b	0.142	0.126	0.125	0.111	0.095	0.079	0.063	0.047	0.032	0.016
R1c	0.100	0.200	0.209	0.300	0.400	0.500	0.600	0.700	0.800	0.900
R2a	0.056	0.050	0.049	0.043	0.037	0.031	0.025	0.019	0.012	0.006
R2b	0.095	0.084	0.084	0.074	0.063	0.053	0.042	0.032	0.021	0.011
R2c	0.051	0.045	0.044	0.039	0.034	0.028	0.022	0.017	0.011	0.006
R3a	0.119	0.106	0.105	0.093	0.080	0.066	0.053	0.040	0.027	0.013
R3b	0.046	0.041	0.041	0.036	0.031	0.026	0.021	0.015	0.010	0.005
R3c	0.129	0.115	0.114	0.101	0.086	0.072	0.057	0.043	0.029	0.014
R3d	0.090	0.080	0.079	0.070	0.060	0.050	0.040	0.030	0.020	0.010
R3e	0.104	0.092	0.091	0.081	0.069	0.058	0.046	0.035	0.023	0.012
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

These results, shown in Table 8 and Figure 3, demonstrate that each weight varies, and the ranking of risk factors shows minor fluctuations.

Table 8 Ranking of each risk factor throughout the sensitivity analysis

Risks Factors	Normal (0.209)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
R1a	8	8	8	8	8	8	8	8	8	8
R1b	2	1	2	2	2	2	2	2	2	2
R1c	1	5	1	1	1	1	1	1	1	1
R2a	9	9	9	9	9	9	9	9	9	9
R2b	6	6	6	6	6	6	6	6	6	6
R2c	10	10	10	10	10	10	10	10	10	10
R3a	4	3	4	4	4	4	4	4	4	4
R3b	11	11	11	11	11	11	11	11	11	11
R3c	3	2	3	3	3	3	3	3	3	3
R3d	7	7	7	7	7	7	7	7	7	7
R3e	5	4	5	5	5	5	5	5	5	5

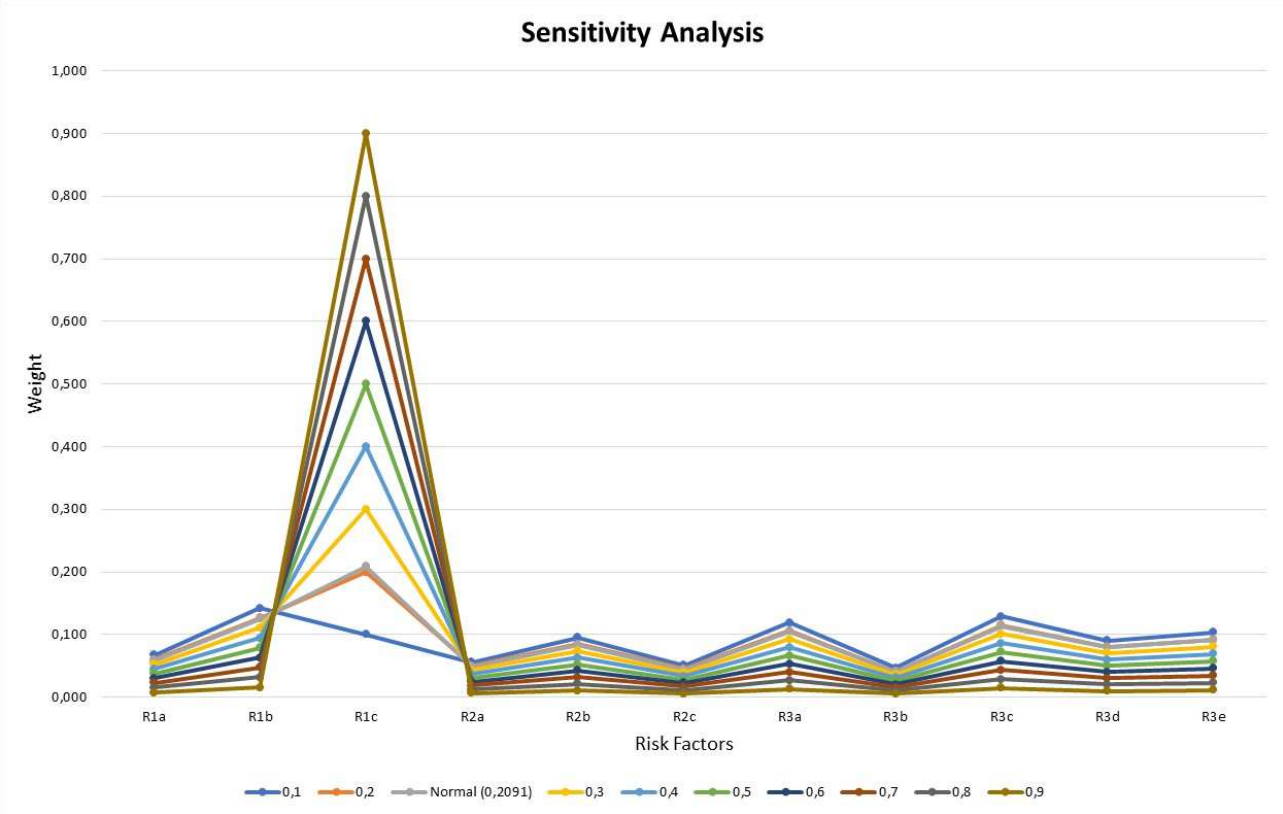

Figure 3 Graph of the weight of each risk factor during the sensitivity analysis

A little difference in the rating was discovered at a weight of 0,1 for the risk factor "quality of the final product (R1c)", with the risk factor "Financial instability (R1b)" receiving the first place, not the second., the risk factor "Government regulation (R3a)" got the position third, not fourth, the risk factor "Degradation of fish population (R3c)" is in second place, not third, the risk factor "Natural disaster (R3e)" is in fourth position, not fifth, and the risk factor "Quality of final product (R1c)" is fifth position, not first. Furthermore, no changes were noted during weight variations of 0.2 to 0.9.

3.4 Theoretical and managerial implications

The research's theoretical and managerial implications are evident. In terms of theory, this research has significantly advanced the field by breaking down the risks associated with the supply chain for smoked skipjack tuna into three categories: internal, operational, and macro-level risk. From a methodological standpoint, this study is the first attempt to use the BWM in risk assessment for agro-food supply chains. Using the BWM, it is possible to assess risk variables quantitatively and get the most accurate and dependable answers.

This research substantially contributes to the practice area in the managerial aspect. The results of this study can

assist professionals in comprehending the risks associated with the skipjack tuna agro-industry supply chain and can direct decision-makers in creating a proactive risk mitigation strategy to manage the risks already present. Based on the research findings, which are summarized as follows, some particular management implications can be developed:

- Tightening the implementation of quality control and cold chain improvement from upstream to downstream. This effort is made to improve the quality and safety of food products involving the supply chain from the production stage (upstream) to the distribution and consumption stage (downstream), such as implementing strict hygiene and sanitation standards in processing areas, as well as using standard equipment that is kept clean.
- Easy access to capital in financial institutions with low interest. With easy access to capital from financial institutions with low-interest rates for agro-industry, it is hoped that more agro-industry will obtain capital to develop their businesses sustainably. This will have a positive impact on economic growth and improving community welfare, such as utilizing the People's Business Credit Program (KUR), microfinancing programs through Savings and Loans Cooperatives or Micro Financial Institutions (LKM), utilizing government programs oriented towards agro-industry.
- Application of measurable fishing policies and selectivity of fishing gear. Applying measurable fishing policies and selectivity of fishing gear is essential to prevent the degradation of fish populations. By paying attention to size, quota, fishing time, and fishing gear used, it is hoped that the fish population can be managed sustainably so that it does not experience a significant decline.
- Formulate a win-win solution policy for all skipjack tuna supply chain actors. This approach can be implemented as 1) Empowering Fish Supply Chain Actors: The government must also empower all fish supply chain actors through education, training, and access to the necessary information and knowledge. By providing adequate skills and knowledge, fish supply chain actors can increase their capacity to manage the fish business, obtain greater profits, and improve product quality. 2) Infrastructure and Technology Development: The government can develop the necessary infrastructure to facilitate fishing, processing, storage, and distribution activities. Improving infrastructure such as fish ports, fish markets, cold storage, and reasonable access roads will help speed up the process and reduce losses in the fish supply chain. In addition, the government must support technological innovation in fishing that is more efficient and environmentally friendly. 3) Fair Price and Profit Setting: The government can set up a fair price-setting mechanism for fishermen to ensure sustainable profits in the fish supply chain. This can be done by avoiding setting meager prices by mediators or market intermediaries.
- Accelerate the application of renewable energy technology for fishermen and agro-industry. Accelerating the application of renewable energy technology for fishermen can help increase productivity, reduce operational costs, and reduce the environmental impact of fishing businesses. The government and related institutions can provide incentives and support to accelerate the adoption of this technology so that fishermen can access renewable energy technology more widely and effectively.

4 Conclusion and future research

The AFSCRA has been carried out using the BWM so that several conclusions can be drawn, namely that there are 11 risk factors identified from the aspects of internal risk, operational risk, and macro-level risk. Using the BWM, the weight importance of each risk factor is obtained, which is a focus for proposed handling strategies. Three risk factors are taken based on ranking as priorities to be handled, including final product quality (R1c) with a weight of 0.29, financial instability (R1b) with a weight of 0.125, and degradation of fish populations (R3c). Furthermore, several managerial implications for more proactive risk mitigation are proposed, including tightening the implementation of quality control and improving the cold chain from upstream to downstream, easy access to capital in financial institutions with low-interest rates, implementation of measured fishing policies, and selectivity of fishing gear, formulating win-win solution policies for all actors in the skipjack tuna supply chain, and accelerating the application of renewable energy technology for fishermen and agro-industry.

There are a few limitations to this study. Using BWM, the eleven risk factors were examined. This study did not examine strategies for risk mitigation that would address identified risk factors. The scope of this study might be increased to examine and find risk-mitigation measures for the most critical risk variables. This research can also be developed by simulating the success of mitigation strategies for risk factors. Furthermore, this research can also be expanded to examine how different risk factors interact in the skipjack tuna supply chain using several MCDM methods such as Total Interpretive Structural Modelling (TISM), Fuzzy DEMATEL, or rough-DEMATEL. In addition, thorough handling is required to apply the suggested technique.

The BWM method is not only used in solving supply chain risk assessment. Still, it can also be applied widely in several research fields, for example, in the manufacturing sector, such as selecting production machines to be purchased, selecting suppliers to supply raw material needs for production, and in the transportation sector such as evaluate port performance measurements.

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Market segment evaluation based on fuzzy tools
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Market segment evaluation based on fuzzy tools

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Keywords: market segment, fuzzy SAW method, fuzzy SBWM, expert linguistic evaluations, Porter's force assessment model.
Abstract: The paper suggests a hybrid model with simplified and extended schemes for evaluating market segments based on strategic diagnostics methods and fuzzy multi-criteria analysis tools. The developed model's novelty and originality consist of forming a system of evaluation criteria based on the GROT criteria of I. Ansoff and the five forces of the M. Porter model (and in the case of an extended calculation scheme – with their decomposition into sets of relevant sub-criteria) and the use of the latest Fuzzy SBWM method (Fuzzy Extension of Simplified Best-Worst Method) to determine their weighting factors. Expert linguistic evaluations on a defined 7-level term set, followed by their transformation into fuzzy numbers with triangular membership functions, are used to evaluate market segments for each identified criteria (sub-criteria). The Fuzzy SAW method determines fuzzy integral estimates of market segments based on these sub-criteria. A practical case of evaluating the confectionery market segments of Ukraine for the simplified calculation scheme is given. The systematic approach makes it possible to determine the attractiveness of market segments for forming strategic recommendations based on the application of portfolio analysis methods, for developing and implementing diversification and logistic strategies.

1 Introduction

Uncertainty, dynamism, and turbulence are characteristic attributes of the modern market environment, which is constantly influenced by various factors that are vague and difficult to predict. This significantly complicates enterprise management processes, especially in a strategic context. Therefore, the management of companies faces the task of developing scientifically based methods of analysis and evaluation and taking into account the trends of the influence of such factors to respond adequately and timely to challenges and use the opportunities generated by the external environment.

Currently, one of the most promising directions of applied research in management, and in particular in strategic management and marketing, is the use of methods and models of the fuzzy-multiple theory, which have a high adaptability to expert data, are sufficiently flexible and adequate to input information.

One of the essential components of management is the evaluation of market segments (MSE) because this characteristic is one of the most critical factors used:

– in the formation of strategic recommendations based on the application of portfolio analysis methods;

– in the development and implementation of diversification and logistic strategies;

– in the formation of investment programs, etc.

As noted by Y. Windand and R. J. Thomas [1], "Market segmentation and evaluation (MSS/MSE) is a critical management decision because all other components of a marketing strategy follow it".

In addition, MSS/MSE plays an essential role in increasing company competitiveness and flexibility in interacting with suppliers in the logistics management of enterprise.

This procedure requires thorough knowledge of logical-causal relationships in the industry and the availability of relevant information about the relevant market segments. As a rule, it is based on expert reasoning and assessments, which have a "blurry", vague character. This, in turn, necessitates revising traditional methods, which need to be more practical considering the nature of available and forecast information and need a more transparent methodology.

2 Literature review

Applying the theory of fuzzy sets and fuzzy logic to solve problems of strategic management and strategic marketing has recently been a growing trend both in scientific literature and in practical activities, significantly expanding the capabilities of classical tools and demonstrating efficiency and flexibility. We will analyze the latest scientific works related to the evaluation of market segments. Authors Duong & Thao [2] propose a TOPSIS model based on entropy and similarity measures for market segment selection and assessment, and a new entropy and similarity measure under a neutrosopic environment is used to evaluate the weights of criteria and the relative closeness coefficient in TOPSIS model.

The proposed fuzzy CODAS method in [3] is applied to an example of market segment evaluation and selection

problem under uncertainty. A comparison between fuzzy CODAS and two other MCDM methods (fuzzy EDAS and fuzzy TOPSIS) is performed to verify the results. Multi-objective optimisation based on the ratio analysis (MOORA) method is applied to solve some market segment evaluation problems [4].

In [5], DEMATEL, CODAS, and Fuzzy Competitive Analysis methods determine the most critical factors in assessing market segments and consider competitive aspects. In [6], a hybrid single-valued neutrosophic multi-criteria group decision-making (MCGDM) approach with quality function deployment (QFD) is used to support the MSS/MSE process.

The authors [7] use Gray Relational Analysis to identify critical relationships between market segments, Fuzzy AHP and the COPRAS-G system for MSE. Sarabia F. [8] proposes a Cost-Benefit Method, Segment-Marketing Mix Profit Matrix, for evaluating market segments regarding cost and benefits using cost-benefit analysis. The systematic approach of Dat et al. [9] consists of Kotler's Criteria, which include the classic criteria of the famous marketer Philip Kotler, product-specific variables, decision support systems for analysis, and decision support systems. Mohammadi's A. [10] approach uses DSS with SPACE Matrix, DNP SPACE, and the Dynamic Network Process method. The hybrid MADM Method with AHP and TOPSIS [11] is another hybrid method that uses multi-attribute decision-making (MADM) with AHP and TOPSIS to evaluate market segments. The indexing Approach, Latent Discriminant Analysis (LADI), and Fuzzy Set Model [12] use indexing, latent discriminant analysis and fuzzy models to evaluate market segments. Fuzzy Attractiveness of Market Entry (FAME) uses fuzzy logic to assess the attractiveness of market entry, providing flexibility in decisions related to market segmentation. These methods represent different approaches to analysing market segments, using both traditional statistical methods and modern, more complex techniques that include fuzzy logic and hybrid models to understand better and evaluate market segments, enabling companies to identify the most attractive market segments to enter or expand their activities.

3 Methodology

In this paper, the tools of strategic analysis, fuzzy-multiple theory and fuzzy multi-criteria evaluation are used to achieve the research goals.

Let us consider some crucial relations and assertions of the theory of fuzzy sets, which will be necessary for solving the tasks of this study.

This paper will use the triangular representation of a fuzzy number. In this article, the tools of strategic analysis, fuzzy-multiple theory and fuzzy multi-criteria evaluation are used to achieve the research goals.

Let us consider some crucial relations and assertions of the theory of fuzzy sets, which will be necessary for solving the tasks of this study.

This paper will use the triangular representation of a fuzzy number $\tilde{A} = (a_1; a_2; a_3)$ (Figure 1) with the corresponding membership functions – formula (1). However, a representation, for example, in a trapezoidal form, can also be used.

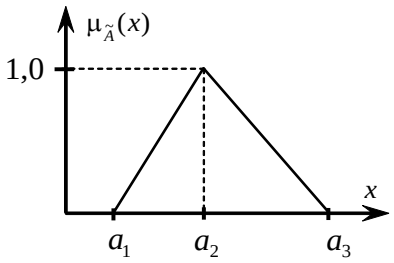

Figure 1 Graphical representation of a fuzzy number with a triangular membership function

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, x < a_1; \\ (x - a_1)/(a_2 - a_1), x \in [a_1; a_2]; \\ (x - a_3)/(a_2 - a_3), x \in [a_2; a_3]; \\ 0, x > a_3. \end{cases} \quad (1)$$

Note that If $\tilde{A} = (a_1; a_2; a_3)$ and $\tilde{B} = (b_1; b_2; b_3)$ – fuzzy numbers, then (2-7):

$$\tilde{A} \oplus \tilde{B} = (a_1; a_2; a_3) \oplus (b_1; b_2; b_3) = (a_1 + b_1; a_2 + b_2; a_3 + b_3), \quad (2)$$

$$\tilde{A}(-)\tilde{B} = (a_1; a_2; a_3)(-)(b_1; b_2; b_3) = (a_1 - b_3; a_2 - b_2; a_3 - b_1), \quad (3)$$

$$\tilde{A} \otimes \tilde{B} = (a_1; a_2; a_3) \otimes (b_1; b_2; b_3) = (a_1 \times b_1; a_2 \times b_2; a_3 \times b_3), \quad (4)$$

$$\tilde{A}(\div)\tilde{B} = (a_1; a_2; a_3)(\div)(b_1; b_2; b_3) = (a_1/b_3; a_2/b_2; a_3/b_1), \quad (5)$$

$$c \times \tilde{A} = c \times (a_1; a_2; a_3) = (ca_1; ca_2; ca_3), c \geq 0, \ c - const, \quad (6)$$

$$c \times \tilde{A} = c \times (a_1; a_2; a_3) = (ca_3; ca_2; ca_1), c < 0, \ c - const. \quad (7)$$

If $\tilde{A}_i = (a_{1i}; a_{2i}; a_{3i})$, $i = \overline{1,n}$, then (8):

$$\oplus_{i=1}^{n} \tilde{A}_i = \oplus_{i=1}^{n} (a_{1i}; a_{2i}; a_{3i}) = (\sum_{i=1}^{n} a_{1i}; \sum_{i=1}^{n} a_{2i}; \sum_{i=1}^{n} a_{3i}) \quad (8)$$

The ratio of the COA (Center Of Area) method (9) is used for the defuzzification of a fuzzy triangular number $\tilde{A} = (a_1; a_2; a_3)$:

$$\tilde{A}^{def} = ((a_3 - a_1) + (a_2 - a_1))/3 + a_1 . \quad (9)$$

The method of fuzzy multi-criteria analysis Fuzzy Extension of Simplified Best-Worst Method (Fuzzy SBWM) [13] is used to solve the problem of calculating weight coefficients of criteria (sub-criteria) for evaluating market segments in this study. Note that BWM was proposed by Rezai J. [14] for multi-criteria decision-making problems based on pairwise comparisons, and in the works of Hafezalkotob A. [15], this method was extended for the theory of fuzzy sets, in particular, using triangular fuzzy numbers.

The integral estimates of market segments are calculated using fuzzy additive weighting (fuzzy SAW method).

I. Ansoff's methodical approach (GROT approach) and P5FM are used to form a system of criteria for evaluating market segments.

4 Result and discussion

To consider subjective, informal, vague input data, opinions and judgments of experts, formulated qualitatively in natural language, a systematic approach developed by the authors is proposed. The main stages are shown in Figure 2.

Let us consider these stages in more detail.

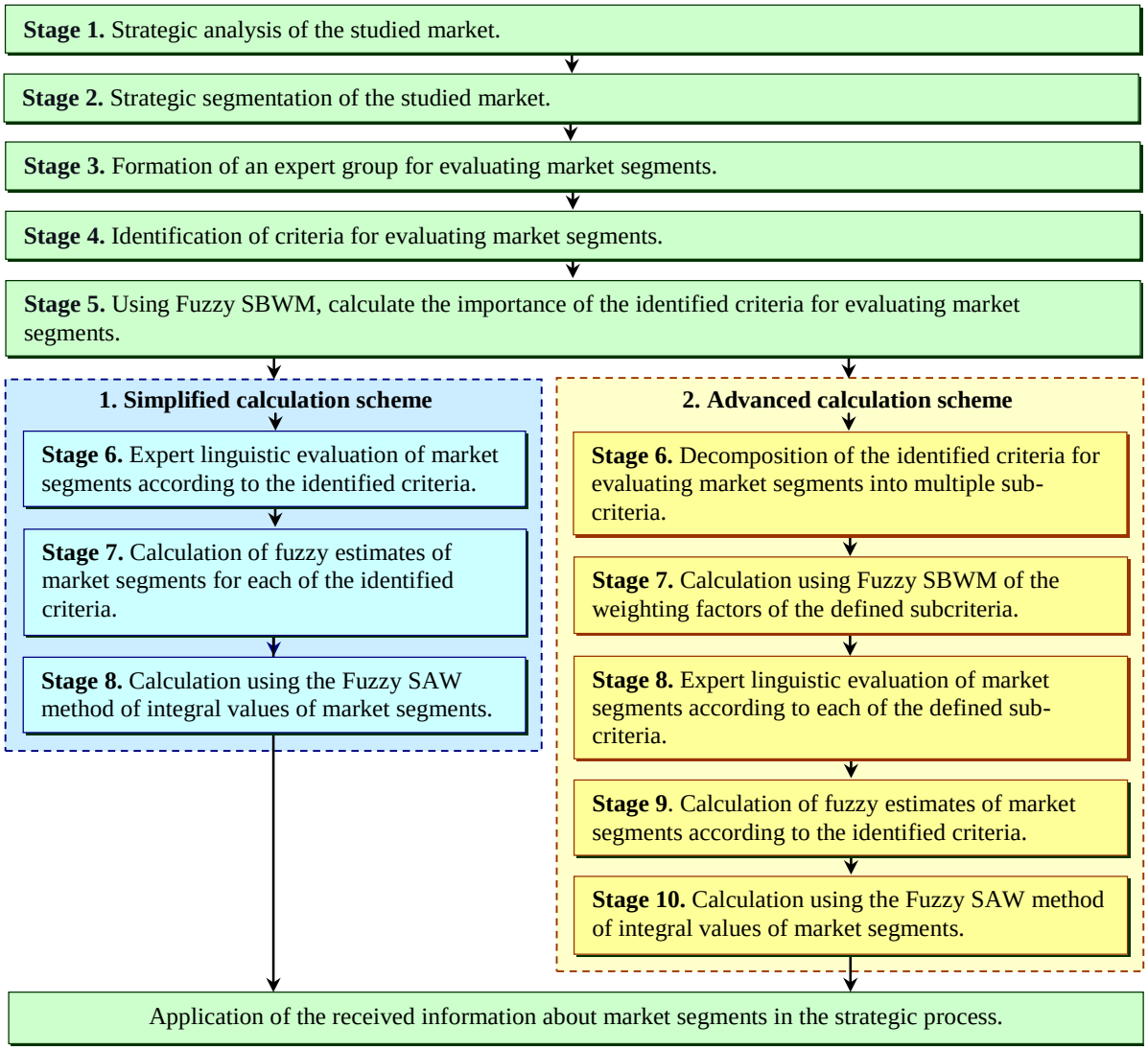

Figure 2 Stages of a methodical approach to the evaluation of market segments (Source: Authors' own)

At stage 1, the company's specialists and analysts, using appropriate tools, conduct a thorough strategic diagnosis of the analysed market, its features and existing trends.

For strategic market segmentation at stage 2, the strategic marketing toolkit or the approach proposed by I. Ansoff [16]is used based on such parameters as need, technology, type of client, geographic area or their combinations. We denote the set of obtained market segments for evaluation by $S = \{S_1; S_2; \ldots; S_n\}$, where is n – their number.

Stage 3 – forming a working group of experts with professional knowledge and experience. Including external experts with relevant competencies and qualifications in the problem area is also appropriate.

Stage 4. Identification of criteria for evaluating market segments.

One of the most critical problems in evaluating market segments is forming a system of evaluation criteria. Consideration of possible solutions to this problem is given considerable attention in scientific literature. Specifically, according to Ou et al. [17], the list of segment evaluation criteria is formed based on P5FM, and they can be modified based on marketing information and retrospective analysis of the implementation of development strategies. Mohammadi. et al. [10] supplement the P5FM toolkit with SPACE analysis criteria. Sarabia F. [8] suggests applying a system of criteria based on the Kaiser criterion and the VARIMAX rotating factor matrix; in particular, management, strategic and segmental criteria groups are highlighted. Based on the generalisation of information from relevant sources, the authors Aghdaie M. et al. [18] proposed the following evaluation criteria: measurability, accessibility, practicality, competitive advantage, segment size, potential profit, expected growth, competition and business strengths. A similar approach to the formation of a system of criteria, additionally using a survey of experts, was also used in Thao N.[19], the following criteria were highlighted: profitability, the growth of the market, size of the market, likely customer satisfaction, sales volume, likelihood of sustainable differential advantage, development opportunities and the differentiation of products. Söllner A. & Rese M. [20]highlight somewhat different criteria in nature and focus: customer response, measurability, accessibility, materiality, and temporal stability. In a study by Dibb et al. [21], the list of criteria consists of two groups: qualifying criteria that determine the feasibility of investments in a segment and attractiveness that assesses the segment's potential. Three groups of criteria are proposed to be used in Tonks D. [22]: design (construct validity (relevance), content validity (relevance), criterion validity (homogeneity/heterogeneity), familiar, universal, requirements of other management functions, data availability, cost); qualification (measurable, accessible, substantial, actionable, stable, parsimonious, profitable, unique response elasticities) and attractiveness (compatibility with corporate objectives, compatibility with company competencies, resource requirements, sales volume, segment growth, relative market share, competitive intensity, entry and exit barriers, macro-environmental factors).

In this study, the authors suggest using (Figure 3) as evaluation criteria:

- ✦ Criteria of the systematic approach of I. Ansoff [16]: – growth prospects (*G*); – rentability prospects (*R*); – favorable opportunities (*O*); – adverse opportunities (threats) (*T*) and
- ✦ Five forces of M. Porter's model [23]: – the bargaining power of customers (*BPC*); – the bargaining power of suppliers (*BPS*); – the threat of new entrants (*TNE*); – the threat of substitute products (*TSP*); – the intensity of competitive rivalry (*ICR*).

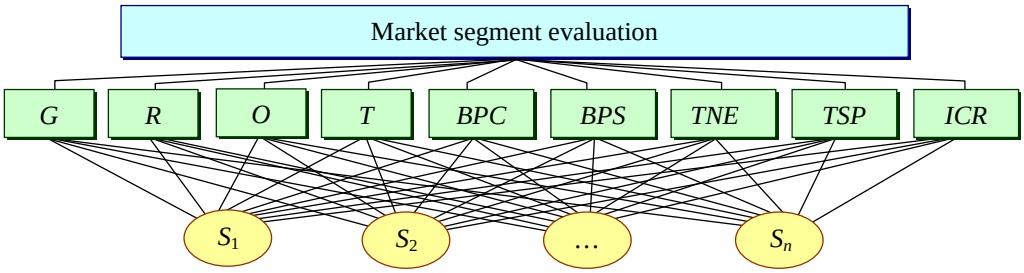

Figure 3 Hierarchy of the problem of evaluating market segments
(Source: Authors' own)

The developed methodological approach involves calculating the importance of the identified criteria for evaluating market segments, which is carried out at stage 5 using Fuzzy SBWM [13; 24]. (Figure 4).

We will redefine the selected criteria for evaluating market segments for the convenience of further application: $G \to C_1$; $R \to C_2$; $O \to C_3$; $T \to C_4$; $BPC \to C_5$; $BPS \to C_6$; $TNE \to C_7$; $TSP \to C_8$; $ICR \to C_9$ and illustrate the application of Fuzzy SBWM in the general case for a set of criteria $C = \{C_1; C_2; \ldots; C_m\}$. It should be noted that the Fuzzy SBWM procedure involves the use of two approaches: the "*best*" approach and the "*worst*" approach, the results of which are combined to determine the integral values of the importance of the investigated criteria (Figure 4).

• Let us first consider the "*best*" approach.

In step 1, it is necessary to determine the most critical ("*best*") criterion among a set of evaluation criteria. It should be done based on a consensus by a group of experts. Let us denote the "*best*" criterion as follows: C_{best}.

Further, in step 2, each of the K experts provides a linguistic evaluation of the importance (priority) of the "best" criterion compared to the other criteria using the terms listed in the Table 1 with corresponding membership functions (Figure 5). It will result in linguistic assessments $L_{jk}^{best}, j = \overline{1,\ m};\ k = \overline{1,\ K}$.

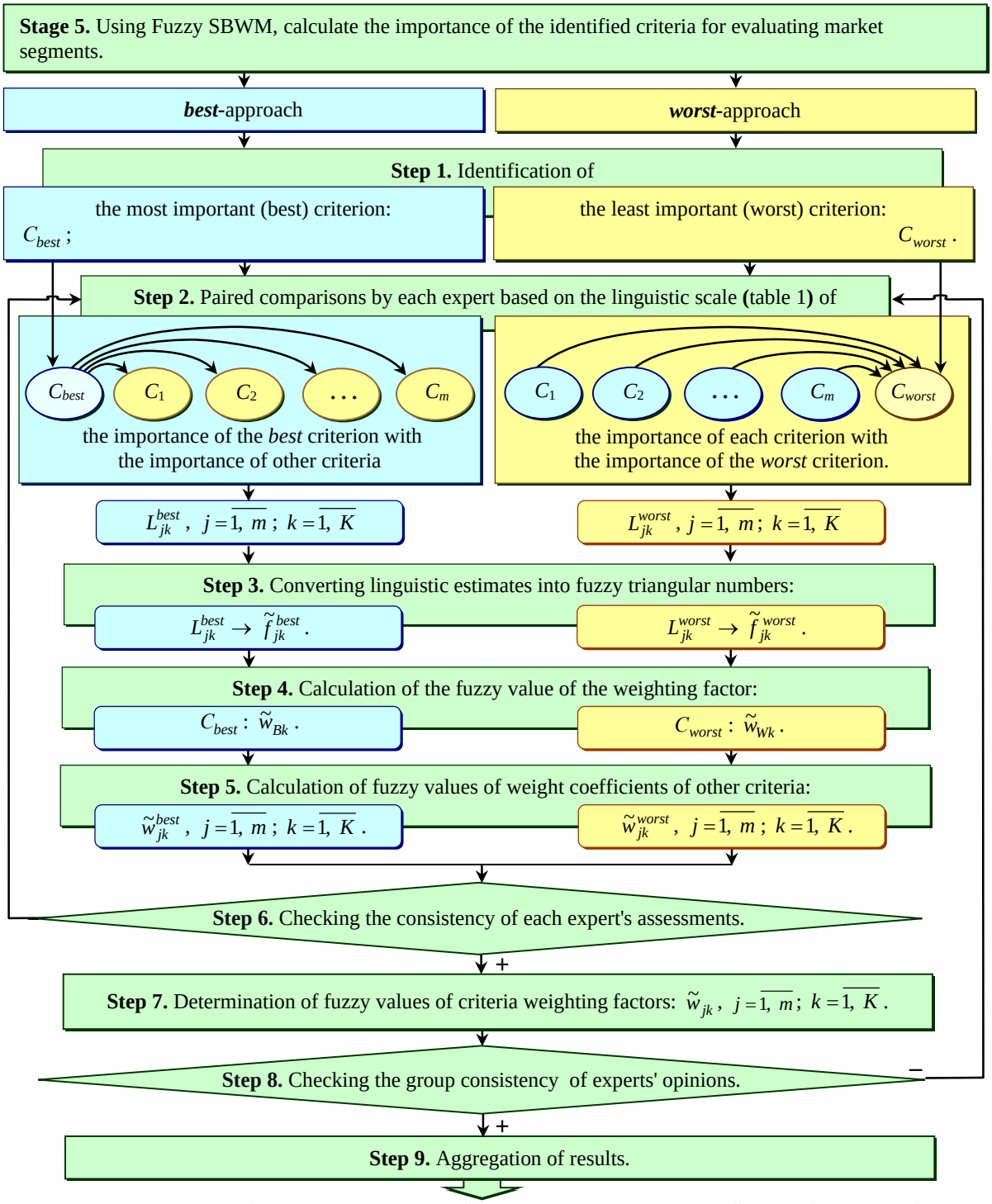

Figure 4 The application scheme of the Fuzzy SBWM method for determining the weighting coefficients of the criteria for evaluating market segments Source: developed by the authors based on [13]

Market segment evaluation based on fuzzy tools
Valeriy Balan, Inna Tymchenko

Table 1 Linguistic terms for evaluating the importance of evaluation criteria and corresponding fuzzy numbers [25]

Linguistic terms for evaluating the importance of criteria (sub-criteria)	Designation	Fuzzy Meaning
Equally	EI	(1; 1; 1)
Weakly	WI	(1; 2; 3)
Moderate	MI	(2; 3; 4)
Moderate plus	MP	(3; 4; 5)
Strong	SI	(4; 5; 6)
Strong plus	SP	(5; 6; 7)
Very strong	VS	(6; 7; 8)
Extreme	EX	(7; 8; 9)

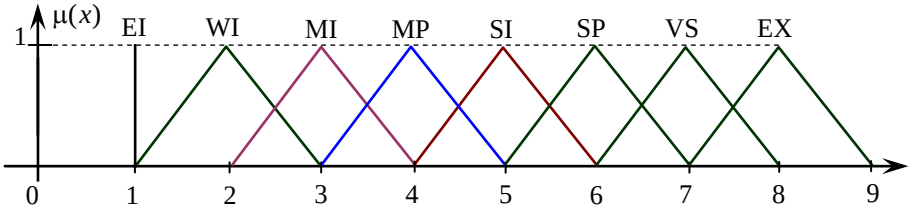

Figure 5 Functions of membership of evaluation terms [25]

Conversion of the obtained estimates L_{jk}^{best} into the corresponding fuzzy triangular numbers (Figure 5) is carried out in step 3 according to the scale of the Table 1 in the form: $\tilde{f}_{jk}^{best} = (\alpha_{jk}^{best};\ \beta_{jk}^{best};\ \gamma_{jk}^{best}),\ j = \overline{1,\ m};\ k = \overline{1,\ K}$.

In step 4, the fuzzy importance value of the "*best*" criterion is calculated using equation (10):

$$\left(\oplus_{j=1}^{m} \frac{1}{\tilde{f}_{jk}^{best}}\right) \otimes \tilde{w}_{Bk}^{best} = 1. \tag{10}$$

From here (11):

$$\tilde{w}_{Bk}^{best} = \frac{1}{\oplus_{j=1}^{m} \frac{1}{\tilde{f}_{jk}^{best}}} = \left(\frac{1}{\sum_{j=1}^{m} \frac{1}{\alpha_{jk}^{best}}}; \frac{1}{\sum_{j=1}^{m} \frac{1}{\beta_{jk}^{best}}}; \frac{1}{\sum_{j=1}^{m} \frac{1}{\gamma_{jk}^{best}}}\right) = (x_{Bk}^{best}; y_{Bk}^{best}; z_{Bk}^{best}) \tag{11}$$

Next, in step 5, since ratios must be performed (12:)

$$\tilde{w}_{Bk}^{best}(-)\tilde{f}_{jk}^{best} \otimes \tilde{w}_{jk}^{best} = 0, \tag{12}$$

then for arbitrary $j = \overline{1, m}$ and for $k = \overline{1,\ K}$ have (13):

$$w_{jk}^{best} = \tilde{w}_{Bk}(\div)\tilde{f}_{jk}^{best} = \left(\frac{x_{Bk}^{best}}{\gamma_{jk}^{best}}; \frac{y_{Bk}^{best}}{\beta_{jk}^{best}}; \frac{z_{Bk}^{best}}{\alpha_{jk}^{best}}\right) = (x_{jk}^{best}; y_{jk}^{best}; z_{jk}^{best}). \tag{13}$$

• For the ***"worst" approach***, in step 1, the least important ("worst") criterion is also determined among the evaluation criteria based on consensus by a group of experts C_{worst}.

In step 2, each *k-th* expert performs a linguistic evaluation of each criterion's importance (priority) compared C_{worst} to the terms listed in the Table 1. As a result, we will obtain L_{jk}^{worst}, $j = \overline{1,\ m};\ k = \overline{1,\ K}$.

In step 3, linguistic assessments are obtained L_{jk}^{worst} transform into corresponding fuzzy triangular numbers according to the scale of the Table 1 in the form $\tilde{f}_{jk}^{worst} = (\alpha_{jk}^{worst};\ \beta_{jk}^{worst};\ \gamma_{jk}^{worst}),\ j = \overline{1,\ m};\ \ k = \overline{1,\ K}$.

Step 4 calculates the importance of the $\tilde{w}_{Wk}^{worst}$ «*worst*»- criterion from equation (14):

$$\left(\oplus_{j=1}^{m} \widetilde{f_{jk}^{worst}}\right) \otimes \tilde{w}_{Wk}^{worst} = 1, \tag{14}$$

From here (15),

$$\tilde{w}_{Wk}^{worst} = 1(\div)\left(\oplus_{j=1}^{m} \tilde{f}_{jk}^{worst}\right) = \left(\frac{1}{\sum_{j=1}^{m} \gamma_{jk}^{worst}}; \frac{1}{\sum_{j=1}^{m} \beta_{jk}^{worst}}; \frac{1}{\sum_{j=1}^{m} \alpha_{jk}^{worst}}\right) = (x_{Wk}^{worst}; y_{Wk}^{worst}; z_{Wk}^{worst}) \tag{15}$$

In step 5, by substituting the weighting factor of the least essential criterion $\tilde{w}_{Wk}^{worst}$ into equation (16), it is possible to calculate the weighting factors of other criteria (17).

$$\tilde{w}_{jk}^{worst}(-)\tilde{f}_{jk}^{worst} \otimes \tilde{w}_{Wk}^{worst} = 0, \text{ for arbitrary } j = \overline{1,\ m};\ k = \overline{1,\ K}. \tag{16}$$

$$\tilde{w}_{jk}^{worst} = \tilde{f}_{jk}^{worst} \otimes \tilde{w}_{Wk}^{worst} = \left(\alpha_{jk}^{worst} \times x_{Wk}^{worst}; \beta_{jk}^{worst} \times y_{Wk}^{worst}; \gamma_{jk}^{worst} \times z_{Wk}^{worst}\right) = (x_{jk}^{worst}; y_{jk}^{worst}; z_{jk}^{worst}). \tag{17}$$

So, in this way, the fuzzy values of the weighting coefficients of all evaluation criteria according to the best- and worst approaches, respectively, were obtained: $w_{jk}^{best} = (x_{jk}^{best}; y_{jk}^{best}; z_{jk}^{best})$ and $\tilde{w}_{jk}^{worst} = (x_{jk}^{worst}; y_{jk}^{worst}; z_{jk}^{worst}),\ j = \overline{1,\ m};\ k = \overline{1,\ K}$.

Next, in step 6, it is necessary to check the consistency of the assessments of each expert. For this, you can use the coefficient CR_k, calculated from the ratio (18):

$$CR_k = def\ \left(\oplus_{j=1}^{m}(\tilde{w}_{jk}^{best}(-)\tilde{w}_{jk}^{worst})^2\right), \tag{18}$$

or by the deviation coefficient according to the formula (19):

$$TD_k = def\left(\oplus_{j=1}^{m}\left(\left(\tilde{f}_{jk}^{best}(-)\frac{\tilde{w}_{Bk}^{best}}{\tilde{w}_{jk}^{best}}\right)^2 \oplus \left(\tilde{f}_{jk}^{worst}(-)\frac{\tilde{w}_{jk}^{worst}}{\tilde{w}_{Wk}^{worst}}\right)^2\right)\right). \tag{19}$$

If the values of the calculated coefficients are significant enough, experts need to revise their estimates of superiority in pairwise comparisons to reach an acceptable range for these coefficients.

If the experts' assessments agree, then at step 7, the fuzzy values of the weighting coefficients of the criteria are calculated as the arithmetic mean of the fuzzy values of the weighting coefficients obtained based on the best- and worst-approaches according to the formula (20):

$$\tilde{w}_{jk} = \frac{1}{2}\left(\tilde{w}_{jk}^{best} + \tilde{w}_{jk}^{worst}\right) = \left(\frac{1}{2}\left(x_{jk}^{best} + x_{jk}^{worst}\right); \frac{1}{2}\left(y_{jk}^{best} + y_{jk}^{worst}\right); \frac{1}{2}\left(z_{jk}^{best} + z_{jk}^{worst}\right)\right) = \\ = (x_{jk}; y_{jk}; z_{jk}). \tag{20}$$

In step 8, it is necessary to check the group consistency of experts' assessments. For this purpose, it is possible to denazify the received values of the weighting coefficients and calculate the concordance coefficient. If necessary, the Fuzzy Delphi procedure can be applied to achieve satisfactory group consistency.

If the group consistency is satisfactory, then at step 9, the results are aggregated according to formula (21):

$$\tilde{w}_j = \frac{1}{K}\oplus_{k=1}^{K}\tilde{w}_{jk} = \frac{1}{K}\oplus_{k=1}^{K}(x_{jk}; y_{jk}; z_{jk}) = \left(\frac{1}{K}\sum_{k=1}^{K}x_{jk}; \frac{1}{K}\sum_{k=1}^{K}y_{jk}; \frac{1}{K}\sum_{k=1}^{K}z_{jk}\right) = (x_j; y_j; z_j) \tag{21}$$

Therefore, the result of stage 5 is the calculated fuzzy values of the weighting factors of the evaluation criteria of market segments.

Next, we will consider two calculation schemes for evaluating market segments: 1. Simplified calculation scheme and 2. Advanced calculation scheme.

✦ For the **Simplified calculation scheme**, at stage 6, an expert linguistic assessment of market segments S_i $(i = \overline{1, n})$ is carried out according to the identified criteria. For this, you can use the following term set TS = {EL; VL; L; M; H; VH; EH} (Table 2, Figure 6):

Table 2 Linguistic terms for estimating market segments and corresponding fuzzy numbers in triangular form (Source: Authors' own)

Linguistic terms for market segment evaluation	Designation	Fuzzy meaning
Extremely High	EL	(1; 1; 2)
Very Low	VL	(1; 2; 3)
Low	L	(2; 3; 4)
Medium	M	(3; 4; 5)
High	H	(4; 5; 6)
Very High	VH	(5; 6; 7)
Extremely High	EH	(6; 7; 7)

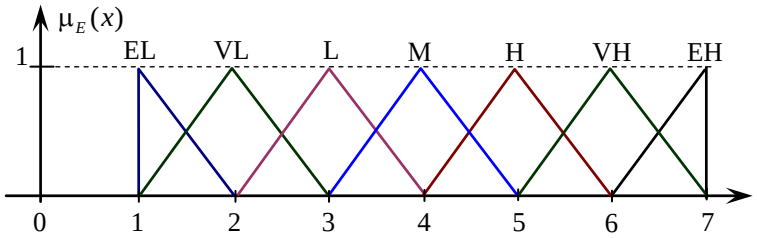

Figure 6 Functions of belonging to the terms of assessment of the level of market segments (Source: Authors' own)

So, let be L_{ijk} – the linguistic assessment by the k-*th* expert of *the* i-*th* market segment according to the j-*th* evaluation criterion. Next, these estimates must be transformed using the triangular form of representation: $L_{ij}^k \rightarrow \tilde{E}_{ij}^k = (a_{ij}^k; b_{ij}^k; c_{ij}^k)$, and check the group consistency of the experts' estimates (for example, by calculating the root mean square deviation); if there are significant differences in them, then it is necessary to revise the corresponding estimates.

At stage 7, the value of market segments according to each of the identified criteria is calculated using the aggregation of the received fuzzy estimates of experts according to the following formula (22):

$$\tilde{E}_{ij} = \frac{1}{K}\oplus_{k=1}^{K}\widetilde{E_{ijk}} = \left(\frac{1}{K}\sum_{k=1}^{K}a_{ijk}; \frac{1}{K}\sum_{k=1}^{K}b_{ijk}; \frac{1}{K}\sum_{k=1}^{K}c_{ijk}\right) = (a_{ij}; b_{ij}; c_{ij}); \quad (22)$$

Further, at stage 8, using the Fuzzy SAW method, we find the integral values of market segment estimates. To do this, first, taking into account the monotonicity of the objective function of each of the criteria (C_1, C_2, C_3 – profit criteria (↗); $C_4, C_5, \ldots, C_9$ – cost criteria (↘)), we normalise the obtained fuzzy values according to the formulas (23-24):

$$\tilde{E}_{ij}^{*} = \frac{\tilde{E}_{ij}}{7} = \frac{(a_{ij};b_{ij};c_{ij})}{7} = \left(\frac{a_{ij}}{7}; \frac{b_{ij}}{7}; \frac{c_{ij}}{7}\right) = (a_{ij}^{*}; b_{ij}^{*}; c_{ij}^{*}) \text{ – for profit criteria (j} = \overline{1,3}), \quad (23)$$

$$\text{and } \tilde{E}_{ij}^{*} = 1(\div)\tilde{E}_{ij} = 1(\div)(a_{ij}; b_{ij}; c_{ij}) = \left(\frac{1}{c_{ij}}; \frac{1}{b_{ij}}; \frac{1}{a_{ij}}\right) = (a_{ij}^{*}; b_{ij}^{*}; c_{ij}^{*}) \text{ – for cost criteria (j} = \overline{4,\leftrightarrows\ 9}). \quad (24)$$

Integral values of market segment estimates are calculated at stage 8 using the formula (25):

$$\tilde{E}_{i} = \bigoplus_{j=1}^{9}\widetilde{w_j} \otimes \tilde{E}_{ij}^{*} = \bigoplus_{j=1}^{9}(x_j; y_j; z_j) \otimes (a_{ij}^{*}; b_{ij}^{*}; c_{ij}^{*}) = \bigoplus_{j=1}^{9}(x_j \times a_{ij}^{*}; y_j \times b_{ij}^{*}; z_j \times c_{ij}^{*}) = \\ = (A_i; B_i; C_i). \quad (25)$$

✦ For the **Advanced calculation scheme**, at stage 6, the identified criteria for evaluating market segments are decomposed into a set of sub-criteria (Figure 7).

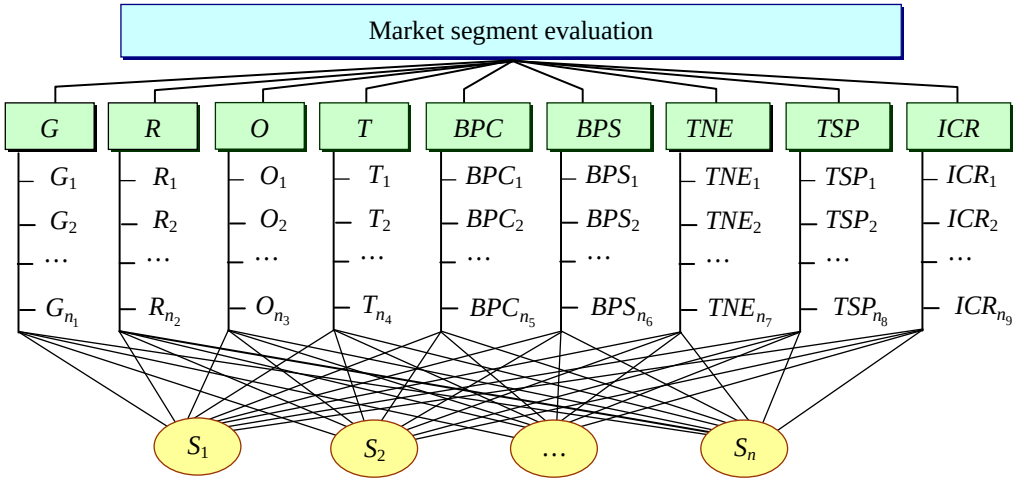

Figure 7 Hierarchy of the problem of evaluating market segments in the Advanced calculation scheme (Source: Authors' own)

Note that the sub-criteria and their number for each evaluation criterion must be determined by the expert group based on the characteristics of the analysed market and its existing trends.

At stage 7, using Fuzzy SBWM, the weighting factors of the defined subcriteria are calculated. Let $\tilde{v}_{jl} = (p_{jl}; q_{jl}; r_{jl})$ be the weighting coefficients of the l-*th* subcriterion of the j-*th* evaluation criterion ($l = \overline{1, n_j}; j = 1,2,\ldots,9$), computed using Fuzzy SBWM.

Stage 8. Expert linguistic assessment of market segments by subcriteria uses the *TS* term set (Table 2). So, let L_{ijlk} be the linguistic assessment by the k-*th* expert of the i-*th* market segment according to the l-*th* subcriterion of the j-*th* valuation criterion. Next, these estimates must be transformed using the triangular form of representation (Table 2, Figure 6): $L_{ijlk} \ \leftrightarrows \rightarrow \tilde{E}_{ijk} = (a_{ijlk}; b_{ijlk}; c_{ijlk})$, and the group consistency of experts' estimates. In the case of a satisfactory result, the aggregation of the obtained fuzzy expert assessments is carried out according to the following formula (26):

$$\tilde{E}_{ijl} = \frac{1}{K}\oplus_{k=1}^{K}\tilde{E}_{ijlk} = \\ \left(\frac{1}{K}\sum_{k=1}^{K}a_{ijlk}; \frac{1}{K}\sum_{k=1}^{K}b_{ijlk}; \frac{1}{K}\sum_{k=1}^{K}c_{ijlk}\right) = \\ (a_{ijl}; b_{ijl}; c_{ijl}). \quad (26)$$

Then, at stage 9, using the Fuzzy SAW method, we find the fuzzy integral values of market segment estimates for each criterion (27):

$$\tilde{E}_{ij} = \bigoplus_{l=1}^{n_j} \tilde{v}_{jl} \otimes \tilde{E}_{ijl} = \bigoplus_{l=1}^{n_j} (p_{jl}; q_{jl}; r_{jl}) \otimes (a_{ijl}; b_{ijl}; c_{ijl})$$
$$= \bigoplus_{l=1}^{n_j} (p_{jl} \times a_{ijl}; q_{jl} \times b_{ijl}; r_{jl} \times c_{ijl}) = (a_{ij}; b_{ij}; c_{ij})$$
$$\mathrm{i} = \overline{1,\mathrm{n}}; \mathrm{j} = 1,2,\ldots,9. \quad (27)$$

Stage 10 of the Advanced calculation scheme is similar to stage 8 of the Simplified calculation scheme. Accordingly, taking into account that C_1, C_2, C_3 – profit criteria, $C_4, C_5, \ldots, C_9$ – cost criteria, formulas (23) and (24) are applied, respectively, to normalize the obtained fuzzy values $\tilde{E}_{ij}$ and further, using formula (25), the integral values of market segment estimates are calculated.

For the practical application of the proposed systematic approach to facilitate the computational process, a framework was developed in Excel containing the following basic units (Figure 8).

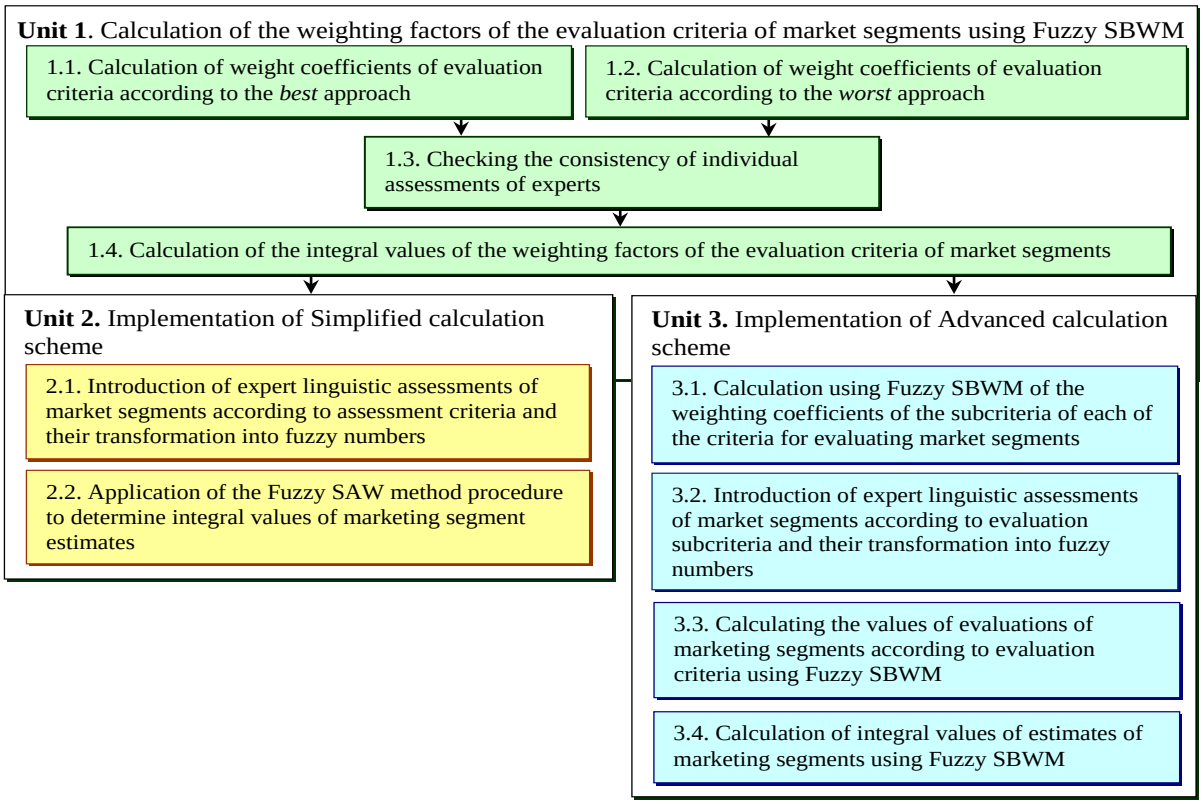

Figure 8 Framework blocks for fuzzy multi-criteria evaluation of market segments (Source: Authors' own)

Case studies. In this study, to illustrate the proposed systematic approach, an evaluation of Ukraine's confectionery market segments will be carried out using the simplified calculation scheme. It should be noted that the Ukrainian confectionery market was formed long ago. A high level of competition characterises it due to many confectionery companies, thanks to which the market has a relatively wide range of constantly updated products that meet consumers' requirements. After the coronavirus pandemic and military aggression conditions, some crucial enterprises in the industry closed. Many enterprises had to reorient to other foreign markets. Moreover, at the same time, due to the decrease in real incomes of the population, its purchasing power decreased, and, as a result, the demand for products fell, which led to a reduction in production volumes. At the same time, trends in the consumption of new products push manufacturers to expand their assortment. The main factors affecting the confectionery market, in addition to those mentioned above, are:

– rising prices for the primary raw materials for confectionery production;
– compliance by manufacturers with higher requirements for production;
– development of the production of promising directions (organic chocolate, diabetic products, etc.);
– reduction of the population in Ukraine;
– expansion of the range of products;
– growth of export orientation in the industry;
– the presence of a significant share of shadow producers on the market;
– the producer's attention to his products and reputation.

In the confectionery market, we will distinguish three main segments: S_1 – the sugary confectionery segment; S_2 – the flour confectionery segment; and S_3 – the segment of cocoa-containing products.

Table 3 shows the linguistic evaluations of five experts according to the scale of the Table 1 of the most critical specified evaluation criteria is in the Table 4 transformed into fuzzy numbers in triangular form.

Table 3 Expert linguistic evaluations of evaluation criteria (Source: Authors' own)

E / C	E_1		E_2		E_3		E_4		E_5	
	best	*worst*	*best*	*worst*	*best*	*worst*	*best*	*worst*	*best*	*worst*
C_1	**best**	SI	**best**	SI	**best**	SI	**best**	SI	**best**	SI
C_2	WI	MP	MI	MI	WI	MP	MI	MI	WI	MP
C_3	MP	WI	MI	MI	MI	MI	MP	WI	MP	WI
C_4	MP	WI	MP	WI	SI	EI	SI	EI	MP	WI
C_5	MI	MI	MP	WI	SI	EI	MP	WI	MP	WI
C_6	WI	MP	MI	MI	MI	MI	WI	MP	WI	MP
C_7	MI	MI	WI	MP	WI	MP	MI	MI	MI	MI
C_8	SI	**worst**	SI	**worst**	SI	**worst**	SI	**worst**	SI	**worst**
C_9	MI	MI	WI	MP	MI	MI	EI	SI	MI	MI

Table 4 Fuzzy evaluations of evaluation criteria when applying best- and worst (Source: Authors' own)

E / C	E_1		E_2		E_3		E_4		E_5	
	best	*worst*	*best*	*worst*	*best*	*worst*	*best*	*worst*	*best*	*worst*
C_1	(1;1;1)	(4;5;6)	(1;1;1)	(4;5;6)	(1;1;1)	(4;5;6)	(1;1;1)	(4;5;6)	(1;1;1)	(4;5;6)
C_2	(1;2;3)	(3;4;5)	(2;3;4)	(2;3;4)	(1;2;3)	(3;4;5)	(2;3;4)	(2;3;4)	(1;2;3)	(3;4;5)
C_3	(3;4;5)	(1;2;3)	(2;3;4)	(2;3;4)	(2;3;4)	(2;3;4)	(3;4;5)	(1;2;3)	(3;4;5)	(1;2;3)
C_4	(3;4;5)	(1;2;3)	(3;4;5)	(1;2;3)	(4;5;6)	(1;1;1)	(4;5;6)	(1;1;1)	(3;4;5)	(1;2;3)
C_5	(2;3;4)	(2;3;4)	(3;4;5)	(1;2;3)	(4;5;6)	(1;1;1)	(3;4;5)	(1;2;3)	(3;4;5)	(1;2;3)
C_6	(1;2;3)	(3;4;5)	(2;3;4)	(2;3;4)	(2;3;4)	(2;3;4)	(1;2;3)	(3;4;5)	(1;2;3)	(3;4;5)
C_7	(2;3;4)	(2;3;4)	(1;2;3)	(3;4;5)	(1;2;3)	(3;4;5)	(2;3;4)	(2;3;4)	(2;3;4)	(2;3;4)
C_8	(4;5;6)	(1;1;1)	(4;5;6)	(1;1;1)	(4;5;6)	(1;1;1)	(4;5;6)	(1;1;1)	(4;5;6)	(1;1;1)
C_9	(2;3;4)	(2;3;4)	(1;2;3)	(3;4;5)	(2;3;4)	(2;3;4)	(1;1;1)	(4;5;6)	(2;3;4)	(2;3;4)

The calculated fuzzy values of the weighting coefficients of the evaluation criteria according to the best and worst approaches of Fuzzy SBWM are shown in Tables 5 and 6. Calculating the coefficients of consistency of each expert's estimates according to formula (18) ($CR_1 = 0.148$, $CR_2 = 0.169$, $CR_3 = 0.132$, $CR_4 = 0.090$, $CR_5 = 0.153$) made it possible to conclude the satisfactory consistency of these estimates $\mathrm{CR_i} < \mathrm{CR}^* = 0.2$. An expert panel selected the value $\mathrm{CR}^* = 0.2$ according to the Fuzzy SBWM methodology.

Table 5 Weighting coefficients of evaluation criteria according to the best approach (Source: Authors' own)

	E_1	E_2	E_3	E_4	E_5
C_1	(0.185;0.270;0.335)	(0.037;0.270;0.335)	(0.191;0.278;0.343)	(0.194;0,246;0,280)	(0,191;0.277;0.341)
C_2	(0.062;0.135;0.335)	(0.046;0.090;0.168)	(0.063;0.139;0.343)	(0.048;0,082;0,140)	(0.063;0.138;0.341)
C_3	(0.037;0.068;0.112)	(0.046;0.090;0.168)	(0.048;0.093;0.171)	(0.039;0.061;0.093)	(0.038;0.069;0.114)
C_4	(0.037;0.068;0.112)	(0.037;0.068;0.112)	(0.032;0.056;0.086)	(0.032;0.049;0.070)	(0.038;0.069;0.114)
C_5	(0.046;0.090;0.168)	(0.037;0.068;0.112)	(0.032;0.056;0.086)	(0.039;0.061;0.093)	(0.038;0.069;0.114)
C_6	(0.062;0.135;0.335)	(0.046;0.090;0.168)	(0.048;0.930;0.171)	(0.065;0.123;0.280)	(0.063;0.138;0.341)
C_7	(0.046;0.090;0.168)	(0.062;0.135;0.335)	(0.063;0.139;0.343)	(0.048;0.082;0.140)	(0.048;0.092;0.170)
C_8	(0.031;0.054;0.084)	(0.031;0.054;0.084)	(0.032;0.056;0.086)	(0.032;0.049;0.070)	(0.032;0.055;0.085)
C_9	(0.046;0.090;0.168)	(0.062;0.135;0.335)	(0.048;0.093;0.171)	(0.194;0.246;0.280)	(0.048;0.092;0.170)

Table 6 Weighting coefficients of evaluation criteria according to the worst approach

	E_1	E_2	E_3	E_4	E_5
C_1	(0.114;0.185;0.316)	(0.114;0.185;0.316)	(0.129;0.200;0.316)	(0.121;0.192;0.316)	(0.118;0.192;0.333)
C_2	(0.086;0.148;0.263)	(0.057;0.111;0.211)	(0.097;0.160;0.263)	(0.061;0.115;0.211)	(0.088;0.154;0.278)
C_3	(0.029;0.074;0.158)	(0.057;0.111;0.211)	(0.065;0.120;0.211)	(0.030;0.077;0.158)	(0.029;0.077;0.167)
C_4	(0.029;0.074;0.158)	(0.029;0.074;0.158)	(0.032;0.040;0.053)	(0.030;0.038;0.053)	(0.029;0.077;0.167)
C_5	(0.057;0.111;0.211)	(0.029;0.074;0.158)	(0.032;0.040;0.053)	(0.030;0.077;0.158)	(0.029;0.077;0.167)
C_6	(0.086;0.148;0.263)	(0.057;0.111;0.211)	(0.065;0.120;0.211)	(0.091;0.154;0.263)	(0.088;0.154;0.278)
C_7	(0.057;0.111;0.211)	(0.086;0.148;0.263)	(0.097;0.160;0.263)	(0.061;0.115;0.211)	(0.059;0.115;0.222)
C_8	(0.029;0.037;0.053)	(0.029;0.037;0.053)	(0.032;0.040;0.053)	(0.030;0.038;0.053)	(0.029;0.038;0.056)
C_9	(0.057;0.111;0.211)	(0.086;0.148;0.263)	(0.065;0.120;0.211)	(0.121;0.192;0.316)	(0.059;0.115;0.222)

Therefore, since each expert's assessments are agreed upon. the integral fuzzy values of the weighting factors of the assessment criteria can be calculated using formula (20) (Table 7).

Table 7 Integral values of the weighting factors of the evaluation criteria (Source: Authors' own)

	E_1	E_2	E_3	E_4	E_5
C_1	(0.149;0.228;0.325)	(0.076;0.228;0.325)	(0.160;0.239;0.329)	(0.157;0.219;0.298)	(0.154;0.234;0.337)
C_2	(0.074;0.142;0.299)	(0.052;0.101;0.189)	(0.080;0.149;0.303)	(0.054;0.099;0.175)	(0.076;0.146;0.309)
C_3	(0.033;0.071;0.135)	(0.052;0.101;0.189)	(0.056;0.106;0.191)	(0.035;0.069;0.126)	(0.034;0.073;0.140)
C_4	(0.033;0.071;0.135)	(0.033;0.071;0.135)	(0.032;0.048;0.069)	(0.031;0.044;0.061)	(0.034;0.073;0.140)
C_5	(0.052;0.101;0.189)	(0.033;0.071;0.135)	(0.032;0.048;0.069)	(0.035;0.069;0.126)	(0.034;0.073;0.140)
C_6	(0.074;0.142;0.299)	(0.052;0.101;0.189)	(0.056;0.106;0.191)	(0.078;0.138;0.272)	(0.076;0.146;0.309)
C_7	(0.052;0.101;0.189)	(0.074;0.142;0.299)	(0.080;0.149;0.303)	(0.054;0.099;0.175)	(0.053;0.104;0.196)
C_8	(0.030;0.046;0.068)	(0.030;0.046;0.068)	(0.032;0.048;0.069)	(0.031;0.044;0.061)	(0.031;0.047;0.070)
C_9	(0.052;0.101;0.189)	(0.074;0.142;0.299)	(0.056;0.106;0.191)	(0.157;0.219;0.298)	(0.053;0.104;0.196)

Further, stage 6 of the Simplified calculation scheme in Table 8 shows expert linguistic evaluations of selected confectionery market segments in Ukraine according to defined evaluation criteria using a linguistic evaluation scale (Table 1).

Table 8 Linguistic assessments by experts of market segments (Source: Authors' own)

		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
E_1	S_1	H	VH	M	M	M	H	M	M	VH
	S_2	VH	VH	M	L	M	H	M	M	VH
	S_3	M	M	VH	VH	L	VH	L	L	H
E_2	S_1	H	VH	L	L	M	M	H	M	H
	S_2	H	H	H	L	L	M	M	H	VH
	S_3	M	VH	H	H	M	H	M	L	M
E_3	S_1	VH	H	H	M	L	L	M	M	H
	S_2	VH	M	M	L	L	M	L	L	H
	S_3	H	M	H	H	L	VH	L	L	M
E_4	S_1	H	VH	M	L	L	M	M	M	VH
	S_2	H	VH	H	VL	M	H	L	M	H
	S_3	M	H	VH	VH	L	H	L	M	M
E_5	S_1	M	H	M	M	L	M	M	M	VH
	S_2	H	H	H	L	L	M	M	L	VH
	S_3	L	H	H	VH	VL	H	L	M	H

Table 9 shows transformed (according to the scale of Table 1) experts' linguistic assessments into triangular fuzzy numbers for each of the areas of analysis.

Table 9 Fuzzy estimates of market segments in a triangular form (Source: Authors' own)

		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
E_1	S_1	(4; 5; 6)	(5; 6; 7)	(3; 4; 5)	(3; 4; 5)	(3; 4; 5)	(4; 5; 6)	(3; 4; 5)	(3; 4; 5)	(5; 6; 7)
	S_2	(5; 6; 7)	(5; 6; 7)	(3; 4; 5)	(2; 3; 4)	(3; 4; 5)	(4; 5; 6)	(3; 4; 5)	(3; 4; 5)	(5; 6; 7)
	S_3	(3; 4; 5)	(3; 4; 5)	(5; 6; 7)	(5; 6; 7)	(2; 3; 4)	(5; 6; 7)	(2; 3; 4)	(2; 3; 4)	(4; 5; 6)
E_2	S_1	(4; 5; 6)	(5; 6; 7)	(2; 3; 4)	(2; 3; 4)	(3; 4; 5)	(3; 4; 5)	(4; 5; 6)	(3; 4; 5)	(4; 5; 6)
	S_2	(4; 5; 6)	(4; 5; 6)	(4; 5; 6)	(2; 3; 4)	(2; 3; 4)	(3; 4; 5)	(3; 4; 5)	(4; 5; 6)	(5; 6; 7)
	S_3	(3; 4; 5)	(5; 6; 7)	(4; 5; 6)	(4; 5; 6)	(3; 4; 5)	(4; 5; 6)	(3; 4; 5)	(2; 3; 4)	(3; 4; 5)
E_3	S_1	(5; 6; 7)	(4; 5; 6)	(4; 5; 6)	(3; 4; 5)	(2; 3; 4)	(2; 3; 4)	(3; 4; 5)	(3; 4; 5)	(4; 5; 6)
	S_2	(5; 6; 7)	(3; 4; 5)	(3; 4; 5)	(2; 3; 4)	(2; 3; 4)	(3; 4; 5)	(2; 3; 4)	(2; 3; 4)	(4; 5; 6)
	S_3	(4; 5; 6)	(3; 4; 5)	(4; 5; 6)	(4; 5; 6)	(1; 2; 3)	(5; 6; 7)	(2; 3; 4)	(2; 3; 4)	(3; 4; 5)
E_4	S_1	(4; 5; 6)	(5; 6; 7)	(3; 4; 5)	(2; 3; 4)	(2; 3; 4)	(3; 4; 5)	(3; 4; 5)	(3; 4; 5)	(5; 6; 7)
	S_2	(4; 5; 6)	(5; 6; 7)	(4; 5; 6)	(1; 2; 3)	(3; 4; 5)	(4; 5; 6)	(2; 3; 4)	(3; 4; 5)	(4; 5; 6)
	S_3	(3; 4; 5)	(4; 5; 6)	(5; 6; 7)	(5; 6; 7)	(2; 3; 4)	(4; 5; 6)	(2; 3; 4)	(3; 4; 5)	(3; 4; 5)
E_5	S_1	(3; 4; 5)	(4; 5; 6)	(3; 4; 5)	(3; 4; 5)	(2; 3; 4)	(3; 4; 5)	(3; 4; 5)	(3; 4; 5)	(5; 6; 7)
	S_2	(4; 5; 6)	(4; 5; 6)	(4; 5; 6)	(2; 3; 4)	(2; 3; 4)	(3; 4; 5)	(3; 4; 5)	(2; 3; 4)	(5; 6; 7)
	S_3	(2; 3; 4)	(4; 5; 6)	(4; 5; 6)	(5; 6; 7)	(1; 2; 3)	(4; 5; 6)	(2; 3; 4)	(3; 4; 5)	(4; 5; 6)

Table 10 presents the calculated fuzzy estimates of market segments according to each of the evaluation criteria and their integral values in a triangular form. The defuzzified fuzzy values of market segment estimates according to the COA (Center of Area) method ratios according to formula (9) are also given in Table 10.

Table 10 Fuzzy estimates of market segments by each of the evaluation criteria. their integral and defuzzified values (Source: Authors' own)

	$\widetilde{W}$	S_1	S_2	S_3
C_1	(0.139; 0.230; 0.323)	(0.571; 0.714; 0.857)	(0.714; 0.771; 0.914)	(0.429; 0.571; 0.733)
C_2	(0.067; 0.127; 0.255)	(0.657; 0.800; 0.943)	(0.600; 0.743; 0.886)	(0.543; 0.686; 0.857)
C_3	(0.042; 0.084; 0.156)	(0.429; 0.571; 0.714)	(0.514; 0.657; 0.800)	(0.629; 0.771; 0.943)
C_4	(0.033; 0.061; 0.108)	(0.220; 0.283; 0.400)	(0.267; 0.367; 0.600)	(0.152; 0.180; 0.220)
C_5	(0.037; 0.072; 0.132)	(0.230; 0.300; 0.433)	(0.230; 0.300; 0.433)	(0.257; 0.350; 0.567)
C_6	(0.067; 0.127; 0.252)	(0.203; 0.257; 0.350)	(0.187; 0.230; 0.300)	(0.157; 0.187; 0.230)
C_7	(0.063; 0.119; 0.233)	(0.193; 0.240; 0.317)	(0.220; 0.283; 0.400)	(0.240; 0.317; 0.467)
C_8	(0.031; 0.046; 0.067)	(0.200; 0.250; 0.333)	(0.213; 0.273; 0.383)	(0.230; 0.300; 0.433)
C_9	(0.078; 0.134; 0.235)	(0.152; 0.180; 0.220)	(0.152; 0.180; 0.220)	(0.187; 0.230; 0.300)
	$\tilde{E}$	(0.201; 0.449; 0.965)	(0.223; 0.470; 1.014)	(0.184; 0.425; 0.968)
	$def(\tilde{E})$	**0.539**	**0.569**	**0.526**

Based on the obtained results, it can be concluded that the segment of flour confectionery S2 has the highest rating, followed by the segment of sugary confectionery S1, and even further, the segment of cocoa-containing products S3.

In this study, the Fuzzy Extension of the Simplified Best-Worst Method is used to calculate the weighting factors of the evaluation criteria (their sub-criteria). This method has several advantages compared to other fuzzy methods of multi-criteria analysis that are used to determine the importance of evaluation criteria, in particular Fuzzy AHP, the multiplicative method of F. Lootsma, etc.: ease of application, a much smaller amount of pairwise comparisons of objects, the presence of two approaches to the calculation of weighting factors.

A significant positive feature of this systematic approach is the presence of two calculation schemes, the first of which (Simplified scheme) can be used in the event of a shortage of time to obtain "quick" assessments of market segments, and the second Advanced scheme with the decomposition of each assessment criterion into multiple sub-criteria - for more thorough and detailed analysis of market segments. Another important aspect is the validity of the proposed model, which is ensured by procedures for checking the consistency of individual expert assessments and the group results.

5 Conclusions

Classic tools for strategic diagnostics of the market environment need improvement due to the ever-increasing complexity and turbulence of the processes occurring in most sectors of national economies. Fuzzy modelling technologies are a modern, potent tool for solving strategic management and strategic marketing problems, as they make it possible to consider and process fuzzy input information about the state of endo- and exogenous factors of dynamic and difficult-to-predict environments.

In this article, the authors have developed a systematic approach to evaluating market segments, which is based on applying the toolkit of fuzzy multi-criteria analysis: Fuzzy Extension of Simplified Best-Worst Method (for calculating the weighting coefficients of evaluation criteria (sub-criteria)) and the Fuzzy SAW method (for determining the evaluations of marketing segments). This approach is implemented in two calculation schemes: Simplified calculation scheme and Advanced calculation scheme. It is proposed to use a combination of I. Ansoff's GROT approach criteria and P5FMare essential for evaluating market segments. In the case of using the Advanced calculation scheme, the decomposition of these criteria into sets of corresponding sub-criteria is assumed.

For the practical application of the approach, a framework has been developed in Excel, which makes it possible to carry out simulation simulations depending on the adjustments of the opinions of experts both at the stage of determining the importance of evaluation criteria (sub-criteria) and when directly evaluating market segments according to them.

According to the authors, the systematic approach can be a relatively flexible and effective tool when conducting strategic market analysis, forming strategic recommendations for industry enterprises based on applying portfolio analysis methods, developing and implementing diversification strategies, forming investment programs, etc.

Further research on this topic can be aimed at the approbation of this systematic approach using the Simplified and Advanced calculation schemes for various industries by adapting the subcriteria to the peculiarities of the studied industries on the application of other methods of fuzzy multi-criteria analysis (Fuzzy TOPSIS, Fuzzy COPRAS, Fuzzy VIKOR, etc.) for the comparative assessment of market segments and the implementation of consistency analysis of the obtained results; for the development of a framework and decision support system using specialised applications that implement the possibilities of fuzzy modelling, for example, the Fuzzy Logic Toolbox package of the Matlab computing system.

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Integrating machine learning and deep learning for enhanced supplier risk prediction

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Abstract: The importance of anticipating and preventing disruptions is underscored by the increased operational complexity and vulnerability caused by advancements in supply chain management (SCM). This has spurred interest in integrating machine learning (ML) and deep learning (DL) into supply chain risk management (SCRM). In this paper, we introduce a tailored method using ML and DL to improve SCRM by predicting supplier failures, thus boosting efficiency and resilience in SC operations. Our method involves five phases focused on classifying and predicting supplier failures in non-conforming deliveries. This involves forecasting failure quantities and estimating total disruption costs. Initially, data from an automotive company is selected, and appropriate potential features and algorithms are selected, performance metric aligns with case study objectives, facilitating method evaluation are used such as: Precision, recall, F1-score, and accuracy metrics assess classification models, while Mean Squared Error (MSE) is used for regression tasks. Finally, an experimental design optimizes models, assessing success rates of various algorithms and their parameters within the chosen feature space. Experimental results underscore the success of our methodology in model development. In the classification task, the Random Forest (RF) classifier achieved 86% accuracy. When combined with the Gradient Boosting classifier, the ensemble exhibited enhanced accuracy, highlighting the complementary strengths of both algorithms and their synergistic impact, surpassing the performance of RF, Support Vector Regression (SVR), k-Nearest Neighbors (KNN), and Artificial Neural Network (ANN). Noteworthy is the performance in regression tasks, where Linear Regression, ANN, and RF Regressor displayed exceptionally low MSE compared to other models.

1 Introduction

To meet delivery deadlines and customer expectations, it becomes crucial for manufacturing companies to predict potential disruptions in their upstream SC caused by non-conforming deliveries. this proactive approach ensures that the assembly process commences as scheduled, ultimately preventing higher production and operational costs.

In essence, non-quality products can trigger a cascade of negative effects, ranging from financial losses and operational challenges for manufacturers to safety risks and dissatisfaction for customers. The increasing intricacy and fragility of SCs underscore the need for enhanced monitoring of SC performance.

Quality issues within the supplier chain can trigger a chain reaction, disrupting the entire SC. This disruption can impede the manufacturer's capacity to source essential components, leading to production schedule disruptions, delays in product delivery, and the potential to compromise customer commitments. manufacturers may find themselves bearing the burden of additional expenses incurred in reworking or scrapping defective products, significantly impacting profitability. Additionally, non-quality products often result in customer dissatisfaction, manifesting as complaints, product returns, and unfavourable reviews.

With the growing accumulation of data and heightened engagement in communication with primary and upper-tier suppliers, it becomes feasible to anticipate and alleviate potential disruptions at a more localized level in the SC. This is particularly relevant given the increasing emphasis on leveraging Big Data (BD) and ML in SCM to gain additional insights into SC operations, ultimately enhancing overall performance and reducing risks [1-6].

Emerging digitalization technologies, including the Internet of Things (IOT) and artificial intelligence (AI), offer new prospects for predicting disruptions in SCM [7-9]. Conducting empirical and sophisticated research is crucial for a deeper exploration of the potential of ML in forecasting and mitigating risks arising from supplier disruptions. Our contribution involves an extensive case study that demonstrates the application of AI techniques in SCM for predicting disruptions. This study specifically concentrates on implementing ML and DL to predict disruptions related to materials from suppliers, with a specific focus on non-quality products. The research emphasis is encapsulated in the following research questions:

Failure Prediction RQ 1: Can we predict which supplier issues are likely to occur in the near future based on historical data, and if so, how can we use this information to prevent them?

Number of Issues Prediction RQ 2: Can we predict how many issues of the same type will occur for a specific failure, which could help in resource allocation and planning?

Total Cost Prediction RQ 3: Given information about a supplier issue, can we predict the total cost incurred by the failure, which would be valuable for cost estimation and budget planning?

These goals and questions establish a robust foundation for our research paper. By concentrating research efforts on quality issues causing SC disruptions, we can significantly reduce risk propagation and its impact on the SC operations. This proactive approach may help in improving supplier performance and maintaining a more resilient and efficient SC.

Each of these prediction questions addresses a specific facet of SC issue management. By homing in on these questions and leveraging AI models, we can offer valuable contributions to the following key areas:

SC risk identification and assessment: ML models enable the prediction and early detection of potential suppliers issues that may occur in the future, aiding in the identification of potential risks that may affect the SC.

Cost Estimation: Drawing from historical data, ML models estimate the cost of supplier issues, providing valuable insights for budget planning.

The structure of the paper is as follows: Section 2 provides a review to the recent progress in predictive data analytics within SCM. Section 3 provides the methodology adopted in accordance with ML and DL models, providing an overview of the case study dataset detailing the chosen algorithms along with their outcomes. Moreover, an evaluation of the performance of our models is conducted. To conclude, a conclusion is presented in the last section.

2 Literature review

Several authors highlight the increasing complexity and global nature of SCs, underscoring the growing significance of anticipating and preparing for disruptions [10,11]. Scholarly discussions have suggested the potential use of predictive algorithms in SCRM [2,12,13] to diminish the influence of a disturbance, there are generally two choices available. The initial choice involves reducing the likelihood of its happening, while the second option aims to establish a robust SC that swiftly reverts to its initial state following a disruption. these alternatives are the focal points of two distinct sectors within SCM, namely, SCRM and SC resilience. within both the broader scope of SCM and its associated fields, data analytics remains a fundamental and integral tool in operations [14]. Data analytics in SCM is characterized by the application of various quantitative and qualitative methods in combination with SCM theory. Its purpose is to address pertinent SCM issues, predict outcomes, and consider factors such as data quality and availability. Additionally, they categorize predictive analytics as a segment of data analytics, specifically focused on enhancing SCs and reducing risks by forecasting potential future occurrences. Conversely, [15] and [16] categorize the existing methods into descriptive, predictive, and prescriptive analytics. descriptive analytics within SCM focuses on comprehending past events [11-13].

Recent research predominantly emphasizes prescriptive analytics over descriptive and predictive analytics within these three categories [4]. However, in line with the standard practice of data analytics, not limited to SCM, the efficacy of prescriptive models is dependent on descriptive and predictive models [3,4]. Consequently, the previously mentioned review papers advocate for further exploration in descriptive and predictive analytics within SCM. Thus, we enhance the current body of knowledge by introducing a case study that highlights the significance of predictive analytics within the field of SCM.

[17-20] emphasize the fundamental role and application of BD and AI plays a crucial role in the procurement process's digital evolution, viewed as a pivotal element for enhancing the competitive edge, effectiveness, and financial success of organizations' SCs. The ever-expanding access to a more extensive range of data in terms of volume, speed, and diversity presents new prospects to transform the influence of data analytics methods [21].Within the broader spectrum of SCM, ML and various data mining methodologies are regularly employed for multiple purposes. These include demand forecasting [22-24] establishing retail prices in SCs and managing financial transactions [25-29]. In the particular realms of procurement and logistics, prior studies primarily focuses on selecting potential suppliers for particular products [30,31]. However, the area of missing materials due to delayed deliveries remains an overlooked aspect of research [32] there is a scarcity of models dedicated to predicting suppliers quality issue. [33] introduced a ML based approach designed to forecast delays in supplier deliveries, the primary focus was on ensuring interpretability to aid decision-making based on the predictions. Utilizing an actual dataset from a multi-tier aerospace manufacturing SC, they conducted a comparison between The effectiveness and clarity of SVM and decision trees (DT) Despite slightly inferior performance metrics, the authors advocated for the use of DT as the preferred ML algorithm, emphasizing their interpretability over performance. [34] conducted a study in an original equipment manufacturer (OEM), where they forecasted delays in deliveries from Tier 1 suppliers by analyzing historical product data. By comparing five ML algorithms, they determined that the RF algorithm demonstrated superior performance when compared to SVM, logistic regression, linear regression, and the KNN algorithm.

Similar to the findings of [33] more sophisticated ML algorithms such as ANN might have demonstrated superior performance but were not explored. Although we acknowledge the importance of incorporating more interpretable ML approaches in SCM, we assert that it is equally crucial to investigate other algorithms like ensemble algorithms or ANN, even if they may pose challenges in terms of interpretability. This exploration is

essential to provide decision-makers with a comprehensive array of options.

Numerous approaches center around data analytics in SCM. However, the exploration of predictive analytics within SCM remains an area that has not received sufficient attention. A particular aspect requiring further investigation is the precise identification and quantification of non-conform deliveries with potential impact for both manufacturers and customers. Existing methodologies in issues related to late and non-conform deliveries face limitations.

Therefore, our contribution to the existing literature comes in the form of a case study in predictive analytics within SCM, employing ML and DL algorithms. Specifically, our focus lies in predicting non conform deliveries from suppliers, employing a supervised learning approach and utilizing an authentic dataset from an automotive manufacturer. In this study, we contrast straightforward ML and DL algorithms such as Random Forest Classifier and Regressor, SVM, SVR, Linear Regression, KNN, and ANN.

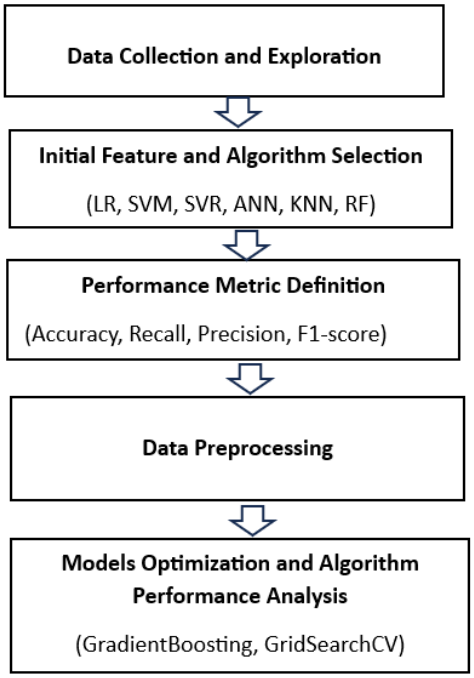

Figure 1 Methodology for predicting supplier risks utilizing ML and DL techniques

3 Methodology

3.1 Case study

The case under study involves a manufacturing company specializing in producing wiring harnesses for numerous OEMs. This company extensively sources millions of components from global suppliers, operating across varied production scales, encompassing both high and low volumes. While individual disruptions, delays, and quality issues remain relatively minor, their cumulative impact can escalate, creating a substantial number of disruptions that demand immediate handling to prevent further propagation.

Consequently, the objective is to establish a predictive system capable of preemptively categorizing potential disruptions and risk before their occurrence. This will facilitate proactive measures for risk mitigation and robust contingency planning, ensuring a proactive and resilient approach to managing and averting potential disruptions.

The focus of our investigation is on pinpointing suppliers most prone to SC vulnerabilities, specifically in terms of delivering bad product quality. As quality issues is a critical area for research. Understanding the impact of these quality issues and their correlation with SC disruptions is key to mitigating risks and ensuring a smoother operational flow. Our principal objective is to identify potential failures originating from suppliers impacted by vulnerabilities, thereby causing disruptions within the SC. We seek to estimate the overall costs associated with inferior-quality products resulting from various disruptions, which include line stoppages, delivery delays, as well as addressing customer concerns and dissatisfaction.

In the pursuit of addressing the complex challenges outlined in our case study, our methodology, in Figure 1, unfolds through a series of designed steps, each contributing to our overarching objective of establishing a predictive system for preemptively categorizing potential disruptions and risks in the SC.

3.2 Data collection and exploration

To comprehend the nuances of disruptions, caused by quality issues within our manufacturing company, we initiated the process with extensive data collection. This involved sourcing historical data from the manufacturer's Enterprise Resource Planning (ERP) system, The data covers supplier quality performance concerning 314 of purchased products over a period of seven years,incorporating assessments from 429 suppliers across 20 manufacturing plants worldwide. key variables within the dataset are outlined in Table 1, that comprising multiple columns containing information relevant to tracking and managing supplier issues. Additionally, each column is accompanied by a specific data format and description, providing insights into the type of information available within the dataset.

The dataset comprises records of 20,000 quality issues associated with distinct products. Among these issues, 53.5% were attributed to suppliers responsible for non-conforming products, 11.46% were linked to suppliers.who refused to acknowledge failures, and 35.04% of issues were communicated to suppliers as information for them to consider and rectify in their future deliveries.

3.3 Initial feature and algorithm selection

Identifying suppliers most prone to vulnerabilities, especially in delivering subpar product quality, was the focal point of our investigation. To translate this focus into actionable insights, we meticulously selected features that

offer critical information about supplier performance, such as supplier name, failure description, issue gravity, number of issue per gravity, and total cost. To elaborate further on our approach, we utilized RF Classifier, SVM, KNN, and ANN for classification tasks, distinguishing and predicting failure descriptions. These models, renowned for their robustness, were instrumental in leveraging historical data to foresee potential disruptions. Concurrently, for regression tasks, specifically predicting the number of issues and total cost, we employed RF Regressor, SVR, Linear Regression and ANN.

As summarized in Table 2. These regression models excel in estimating numerical values, providing valuable insights into the expected quantity of failures and associated costs.

3.4 Performance metric definition

The incorporation of performance metrics is essential in evaluating the effectiveness of our models in addressing supplier quality concerns. In line with the case study's overarching goal of estimating failures, their numbers, and associated total costs, we have defined key performance metrics. These metrics (1), (2), (3), (4), (5), provide a comprehensive assessment of the models' predictive capabilities and their ability to contribute meaningful insights to SCM.

Table 1 Overview of the data

Data	Format	Description
ID number	Alphanumeric	Unique code describing supplier issue
Final Customer	Text	Short description of the final customer
Supplier PN	Alphanumeric	Unique supplier product number
Supplier Name	Text	Short description of the supplier's name
Failure Description	Text	Short description of the failure
Issue Gravity	Alphanumeric	Indicating where the product is detected as non-conform. It has three possible values: • C1: At the final customer • C2: At the manufacturer's plant production process • C3: At the manufacturer's plant in their incoming inspection
Number of issue per gravity	Number	How many issues from same failure were occurred
Supplier Acceptance	Binary	Indicating the acceptance of the supplier for the claimed failure (1 for "Accepted," 0 for "Not accepted")
Plant Location Number	Number	Number of the plant where the failure was detected
City	Text	Representing the city where the plant is located
NOK parts number	Number	Indicating the number of non-conform parts
Creation date	Date	When the failure was detected in the manufacturer's plant
NOK parts replacement	Binary	Representing whether the supplier ensured the replacement of non-conform parts (1 for "Yes," 0 for "No").
Replacement time	Number	Indicating how long the replacement process takes
Recurrent Issue	Binary	Did the issue have been occurred before (1 for "recurrent," 0 for "Not recurrent").
Total Cost (Euros)	Number	Representing the disruption cost incurred by the failure
Invoice Payment	Binary	Indicating if the supplier takes charge of the invoice payment (1 for "Yes," 0 for "No")
Response time	Binary	Indicating if the payment is made in time or not (1 for "Yes," 0 for "No").
Additional Time	Number	Indicating how long the payment takes in delay.

Table 2 ML and DL algorithms selection for regression and classification tasks

Machine Learning /Deep learning Algorithms	Random Forest Classifier	Random Forest Regressor	Support Vector Machine (SVM)	Support Vector Regression (SVR)	Linear Regression	KNN	ANN
Regression (for Number of issue prediction and Total cost)		**x**		**x**	**x**		**x**
Classification (for Failure prediction)	**x**		**x**			**x**	**x**

Precision (1): reflects the accuracy of positive predictions made by the model. In the context of our case study, precision signifies the proportion of correctly identified supplier failures out of all predicted failures.

$$Precision = \frac{True\ Positives}{True\ Positives + False\ Positives} \quad (1)$$

Recall (2): also known as sensitivity measures the model's ability to identify all actual supplier failures. It highlights the proportion of correctly identified failures out of the total actual failures.

$$\text{Recall (Sensitivity)} = \frac{True\ Positives}{True\ Positives + False\ Negatives} \quad (2)$$

F1-score (3): is the harmonic mean of precision and recall. It provides a balanced assessment of a model's performance by considering both false positives and false negatives.

$$F1\ Score = 2 * \frac{(Precision * Recall)}{(Precision + Recall)} \quad (3)$$

Accuracy (4): represents the overall correctness of the model's predictions, defined as the ratio of correct predictions to the total number of predictions.

$$Accuracy = \frac{Total\ Number\ of\ Predictions}{Number\ of\ Correct\ Predictions} \quad (4)$$

Mean Squared Error (MSE) (5) metric for regression tasks : It measures the average squared difference between the predicted values $\hat{y}_i$ and the actual y_i.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2 \quad (5)$$

3.5 Data pre-processing

After gaining insights into the dataset, our next step involved refining it for our predictive models. Initially, we converted categorical data into a numerical format, a prerequisite for ML and DL models that commonly process numerical input. One-Hot-Encoding, a widely established technique, was employed for this purpose. Incorporating dates as input features in a supervised learning framework involves training the prediction model on historical dates along with other relevant features depending on the target variable that we want to predict. In an effort to optimize the model's effectiveness, interpretability, and efficiency, we carefully chose a subset of features from our dataset. The identification of features required an understanding of the influence, correlation, and connections between variables, offering insights into their interdependencies and potential impact on the target variables. To mitigate interdependencies among our input features, certain variables were excluded.

Furthermore, and in order to enhance the performance of ML and DL models by ensuring the data is well-suited for analysis and model training. In summary, we chose the following independent variables to serve as input features for our models: Number of issue per gravity, Total cost, Issue gravity, Failure description, and Creation date.

The pair plot highlights a robust positive correlation among number of issue per gravity, failure description, and total cost, suggesting that a greater frequency of reported issues in failure description (as depicted in Figure 2) is linked to higher total costs.

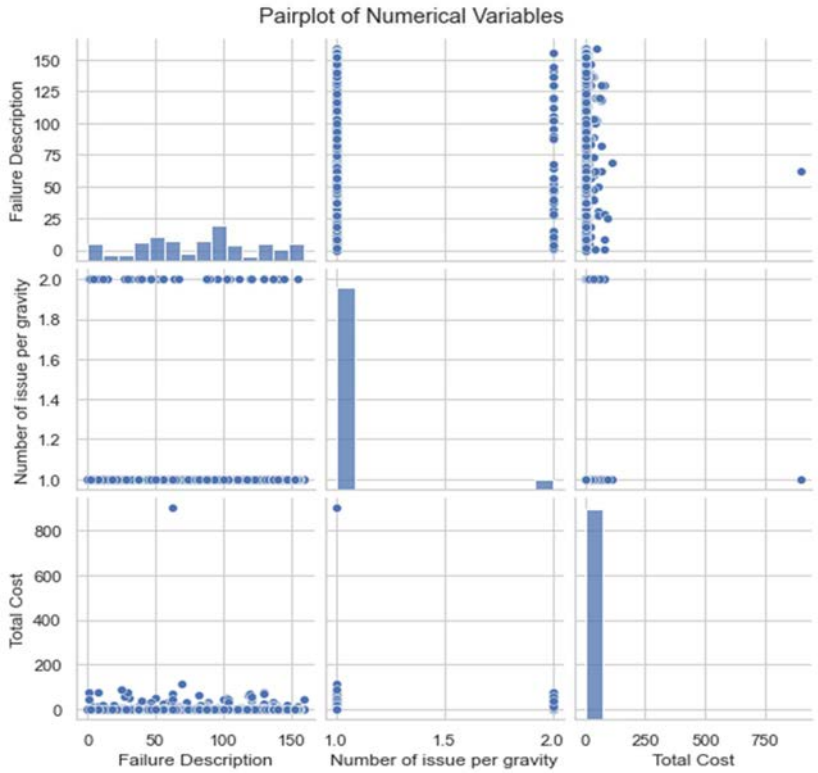

Figure 2 Analysis of issue frequency, failure description and total cost

Furthermore, the correlation observed between number of issue per gravity and total cost underscores that the gravity type occurring more frequently is associated with higher cost implications. This finding suggests that issues of this gravity type, identified by the end customer, are more likely to result in cost generation. Notably, these customer-detected failures, although occurring less frequently than C2-type issues, exhibit a heightened propensity to generate costs.

Following the specification of input features for various prediction models, the data preparation phase was successfully concluded. After understanding the available data and outlining the features for our models, we established an experimental plan consisted of two stages. The first stage focused on a classification task for predicting supplier failures description, where we can answer RQ 1. The second stage is focused on regression tasks for predicting the number of issues and total cost prediction and thus is designed to answer RQ 2 and RQ 3.

4 Result and discussion

This section unveils the findings of our investigation into predicting failure descriptions, a critical task for anticipating and managing potential disruptions in the SC. The accurate classification of failure scenarios holds the key to informed decision-making and proactive risk mitigation in SC operations. Our study delves into the performance of diverse ML and DL models, shedding light on their effectiveness in enhancing predictive capabilities.

4.1 Models optimization and algorithms performances analysis

4.1.1 Classification models optimization

After conducting an in-depth analysis, we explored hyperparameter tuning and feature engineering for both the KNN and SVM models. This rigorous exploration aimed to fine-tune the models and enhance their predictive capabilities.

Grid search is used to find the optimal hyperparameters, which are then used to train a final SVM model. The optimal settings for "C" (regularization parameter) and "kernel" are used to instantiate the SVM model. This improved SVM model is then used to generate predictions for cross-validation. By using an iterative procedure, the model's prediction accuracy and generalization ability are improved by training it with the most efficient hyperparameters found by grid search. As a result of these efforts in Table 3, the SVM model achieved a significant accuracy of 75%, showcasing the impact of parameter optimization.

As well, with hyperparameter optimization, the KNN model showed progress, with an accuracy of 60%. To optimize the KNN model, grid search is used, which entails examining a parameter grid that includes 'n_neighbors,' which is the number of neighbors taken into account for classification. Furthermore, a variety of weight functions ('weights') and distance metrics ('p') are methodically examined. Finding the ideal hyperparameter configuration to enhance classification accuracy is the goal of the grid search process. Five-fold cross-validation is used in conjunction with this optimization procedure to ensure strong assessment and reduce overfitting.

The combination of hyperparameter tuning and feature engineering contributes to a more refined and effective modeling approach, addressing specific characteristics of the dataset and improving overall models performance.

As well, we refined the neural network architecture employed in this task,this architecture consists of two hidden layers with ReLU activation functions, followed by dropout layers with rates of 0.5 and 0.3. The Adam optimizer is employed with default parameters, and training occurs over 100 epochs with a batch size of 32,strikes a balance between complexity and generalization performance, validated through empirical experimentation, providing us with an accuracy of 33%.

Applying advanced hyperparameter tuning techniques, we meticulously fine-tuned the RF to achieve superior performance. The initial RF model yielded an accuracy of 62%. Subsequently, we conducted an exhaustive hyperparameter search using GridSearchCV, exploring a parameter grid. This process resulted in a refined RF model with an enhanced accuracy of 64%, illustrating the significance of hyperparameter optimization.

In addition, we delved into the potential of Gradient Boosting to further boost model performance.

To find the ideal set of hyperparameters from the specified parameter distributions, RandomizedSearchCV is utilized. random sampling from the parameter distributions is done ten times.every possible combination of hyperparameters is assessed using 5-fold cross-validation.

The Gradient Boosting classifier exhibited exceptional accuracy, reaching an impressive 86%. This success highlights the effectiveness of Gradient Boosting in capturing intricate patterns within the data and maximizing predictive accuracy.

These detailed efforts in hyperparameter tuning, utilizing GridSearchCV for the RF model and configuring Gradient Boosting, showcase our commitment to optimizing model performance and uncovering the most effective configurations for the given classification task.

After the model is fitted, we carry out the validation set evaluation and cross-validation.Understanding the model's expected performance in real-world with unseen data. Using a 5-fold cross-validation, the cross-validation scores vary from 85.38% to 87.26%, with an accuracy of 86.39% on average and a standard deviation of 0.77%. The efficacy of the Gradient Boosting classifier in forecasting the failure descriptions within the dataset is exhibited by these outcomes.The model has strong performance on the validation set as well as in cross-validation, suggesting that it can generalize well to previously unseen data from the same distribution as the training data.

Table 3 Model evaluation metrics for classification task related to failures prediction

Model	Accuracy	Macro Avg Precision	Macro Avg Recall	Macro Avg F1-Score	Weighted Avg Precision	Weighted Avg Recall	Weighted Avg F1-Score
KNN	**60%**	**0.21**	**0.23**	**0.21**	**0.52**	**0.60**	**0.55**
SVM	**75%**	**0.35**	**0.35**	**0.34**	**0.75**	**0.75**	**0.75**
ANN	**33%**	**0.14**	**0.14**	**0.12**	**0.29**	**0.33**	**0.28**
RF classifier	**62%**	**0.26**	**0.30**	**0.27**	**0.54**	**0.62**	**0.56**
RF classifier with GridSearchCV	**64%**	**0.28**	**0.32**	**0.28**	**0.55**	**0.64**	**0.58**
RF classifier with Gradient Boosting classifier	**86%**	**0.58**	**0.59**	**0.58**	**0.78**	**0.82**	**0.79**

Table 4 Model evaluation metrics for regression task related to number of failures prediction

Regression (Metrics/Models)	ANN	Linear Regression	Random Forest Regressor	SVR
MSE 'Number of Failures'	**2.681293342490944e-16**	**1.87e-33**	**0.0001**	**0.05**

Table 5 Model evaluation metrics for regression task related to total cost prediction

Regression (Metrics/Models)	Linear Regression	Random Forest Regressor	ANN	SVR
MSE 'Total Cost'	**1.56e-28**	**0.023**	**0.17**	**0.88**

In addition, to assessing the performance metrics of our models, we conducted an in-depth analysis of feature importance to identify the input features that significantly influence the model's output. This exploration provides valuable insights into the variables driving the predictive capabilities of our models.

The results of our feature importance analysis underscore the pivotal role of specific variables in the prediction of failure descriptions. Notably, supplier name and failure description emerged as features with higher importance compared to others in the models for the initial stage. These variables exert a substantial influence on the accurate prediction of the failure description, aligning with the nuances of our SC disruption prediction task.

The identification of influential features enhances our understanding of the underlying dynamics of failure prediction. These insights can inform decision-makers in the SC, enabling them to focus on key variable for improved risk assessment and proactive mitigation strategies.

4.1.2 Regression models performance analysis

This part presents a detailed analysis of the performance metrics for the regression models employed in predicting the number of failures and total cost respectively in Table 4 and Table 5. The models considered include Linear Regression, SVR, RF Regressor, and ANN evaluated through MSE metric.

In our quest to predict the number of failures, Our analysis reveals noteworthy insights into the performance of various regression models. Linear Regression and the ANN stand out with unprecedented in conclusion, our research, which delves into the predictive capabilities of ML and DL models, significantly contributes to the proactive prevention of SC disruptions and the enhancement of supplier performance. By focusing on specific prediction questions, our study empowers decision-makers with valuable insights for issues prevention, risk control, and supplier management. The integration of predictive analytics and innovative methodologies, as explored in our research, empowers organizations to navigate the complexities of the modern SC landscape with heightened efficiency and effectiveness. This convergence of SCM with advanced technologies establishes a foundation for a more resilient and adaptive future in SC operations. By leveraging predictive capabilities, organizations can proactively respond to emerging challenges and uncertainties, ensuring a robust and future-ready SC.

However, it's essential to acknowledge the limitations of our study. Future research could explore additional industry-specific datasets and address potential biases in the selected data. Additionally, the ethical considerations of deploying advanced technologies in SCM, such as data privacy and algorithmic transparency, warrant continued attention as organizations embrace these predictive capabilities,predictive accuracy, boasting MSE values of 1.87e-33 and 2.681293342490944e-16, respectively. These exceptionally low errors underscore their remarkable precision in capturing the underlying patterns in the data. SVR demonstrates a commendable performance, striking a balance with an MSE of 0.05,

indicative of solid predictive capabilities. Notably, the RF Regressor emerges as the top performer, showcasing an exceptionally low MSE of 0.0001. This outstanding result underscores its prowess in capturing intricate relationships within the data, making it a robust choice for regression tasks.

Furthermore, our detailed investigation into feature significance for our selected models, particularly the RF Regressor, identified gravity issue and number of issues per gravity as key variables with notably elevated importance compared to others in the second-stage models. These findings emphasize the crucial roles of these variables in predicting the number of issues per gravity, highlighting their substantial importance in our SCM context.

To predict the total cost, Linear Regression continues to demonstrate an exceptionally low MSE of 1.56e-28 for predicting total cost. This indicates very high accuracy and precision in its predictions. The ANN model has an MSE of 0.17, indicating acceptable performance. While higher than the MSE for Linear Regression. The RF Regressor has an MSE of 0.023, which is higher than Linear Regression but lower than the ANN. SVR has the highest MSE among the models, with a value of 0.88. This indicates a higher level of prediction error compared to the other models.

[35] The authors employed a variety of regression models, including Simple Regression, Lasso Regression, Ridge Regression, Elastic Net, RF, Gradient Boosting Machine (GBM), and Neural Network, to predict the availability of products in the event of disruption. The results of their experiments showed that tree-based learning algorithms,RF and GBM in particular,performed better than other models in terms of test error.

Overall,the type of data used and the features chosen for the study have an impact on the models' performance. Regression models can exhibit variability in their responses to distinct data sets and feature types.Neural networks can perform very well in scenarios with enormous datasets or sophisticated feature interactions because of their great degree of flexibility and ability to understand complex patterns in data. Nevertheless, they may be more prone to overfitting and need careful hyperparameter adjustments, particularly in cases when the dataset is noisy or tiny.In conclusion, elements including the type of data, the attributes of the features, and the intricacy of the underlying relationships all have an impact on the model selection and performance.

5 Conclusions

In summary, our research underscores the pivotal role that ML and DL models play in transforming SCM.By delving into the predictive capabilities of these models, we contribute significantly to the proactive prevention of disruptions in the SC and the overall improvement of supplier performance.

Our study's value lies in its specific focus on prediction questions, providing decision-makers with actionable insights for preventing issues, controlling risks, and managing suppliers more effectively. Through the integration of predictive analytics and innovative methodologies, as explored in our research, automotive organizations gain the tools necessary to navigate the intricate landscape of modern SCs with heightened efficiency.

This convergence of SCM with advanced technologies establishes a robust foundation for a more resilient and adaptive future in SC operations. leveraging predictive capabilities empowers organizations to proactively respond to emerging challenges and uncertainties, ensuring a SC that is both robust and future-ready.

The specific automotive data provides several strengths, it allows for a deep understanding of the nuances and intricacies within the automotive SC. The models developed based on this data are likely to be highly tailored to the specific challenges and dynamics of the automotive industry. This specialization can lead to more accurate predictions and insights, particularly for disruptions related to non-quality products from suppliers. Despite its resilience, the dynamics, challenges and variables influencing disruptions in the automotive SC may be very different from those in other sectors.Compared to businesses like electronics or pharmaceuticals, the automobile sector could have different procurement procedures, product lifecycles, or regulatory needs. As a result, models created using data from the automobile industry might not be directly applicable or accurate in other SC scenarios or industries. It's essential to validate the models developed using data from different industries or SC contexts. This validation process may involve testing the models with data from companies in other sectors and making necessary adaptations or adjustments to ensure their effectiveness and accuracy. Furthermore,the research focus on predicting disruptions from non-quality products while excluding other types of disruptions such as logistical issues and geopolitical events. Logistical issues could involve problems with transportation, warehousing, or distribution, while geopolitical events could include trade disputes, political instability, or natural disasters impacting and changing SC dynamics that can be influenced by a wide range of factors the assumption of stationarity may no longer hold true.Changes in SC dynamics can alter the underlying patterns and relationships in the data used for modeling and forecasting.For instance,supplier performance may change, or new SC partners may be introduced. These changes can affect the model’s accuracy and the statistical properties of the data, making it more challenging to accurately predict future outcomes using traditional stationary models.

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A survey study on Industry 4.0 for Moroccan manufacturing
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A survey study on Industry 4.0 for Moroccan manufacturing

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Keywords: Industry 4.0, survey, smart factory, technology implementation.
Abstract: In this article, a field study is conducted to analyze the state of enterprises in Morocco in the face of digitalization by studying large, small, and medium-sized enterprises. This study focuses mainly on researching the factors that influence their decision to adopt a digital strategy. Using the AHP multi-criterion method, a precise selection was made based on the opinions of experts in the field. To make this choice, a precise methodology was used: brainstorming and a weighted vote. An online survey was conducted, and 34 companies were interviewed to analyze the ways in which they are adopting digitalization, to present the most commonly used digital tools, and to study the impact, benefits, and obstacles of a digital strategy. A data analysis was applied by combining R with SPSS. The findings of this study show that Morocco is beginning to incorporate digitization into its practices, and more precisely, into the supply chain's operations, but that this use is still quite limited to certain tools and practices. They emphasize the underlying causes, highlight the benefits of digitization, and compare the levels of corporate maturity compared to digital. Six factors have been identified to influence this decision. This article contributes to an existing gap in empirical studies that highlight the integration of digital strategies, focusing on the case of Morocco. It provides useful data that can significantly improve management methods and encourage the integration of digital strategies, regardless of their size, making it a significant contribution to researchers and even industries.

1 Introduction

Today's companies face numerous constraints and challenges daily, requiring flexibility and innovation to remain competitive.

With the advent of the fourth industrial revolution, companies of all sizes face the challenge of digitizing their processes, which enables them to exchange data in real time, increase productivity, enhance process quality, and achieve financial gains (1-2). This challenge has prompted many companies to join the digital transformation over the past ten years.

After a bibliographical study, we noted that some works were published that treat the state of the companies compared to the digital in various countries, like the works of (3), which focus on the SME of New Zealand; the works of (4), which work on the case of the Italian SME, for example; and (5), which work on German SMEs. However, no work has been found in Morocco, which motivates us to work in this direction. However, this work is unique in that it deals with the same theme, is based on the case of Morocco, and focuses on large companies and SMEs at the same time.

In this paper, we study the current state of digital companies in Morocco to find out where they stand regarding Industry 4.0, why companies resist introducing it for several reasons, and how they can move towards a "4.0" environment efficiently. Companies adopt digitization strategies by focusing on the factors that influence the use of various digitization tools in the supply chain. This study examines these tools and the influencing factors.

We surveyed large companies and SMEs to collect data on the state of digitization in Moroccan companies. Our population consists of industrial executives with extensive knowledge and visibility into their companies' digitization strategies.

This work's primary goal is to examine the state of companies in Morocco facing digitalization. We have set up two research questions to clarify our main problem.

RQ1: In terms of 4.0, where are Moroccan enterprises?

RQ2: What are the digitization tools used by these companies?

This document is organized into sections. Section 2 presents the survey methodology used to achieve the study objectives, the sample characteristics, and the data collection and analysis process. Section 3 presents detailed results concerning our target's organizational factors, the various impacts and benefits of adopting digitization 4.0 tools, a vision of the digital strategy adopted, and the different elements influencing the latter's choice.

Section 4 presents a discussion of the results, the main conclusions of the interviews, and future developments.

2 Literature review

The term Industry 4.0 appeared for the first time in the German strategic plan for new technologies (5–6). It designates the fourth industrial revolution, which is characterized by data analysis, the automation of manufacturing processes, and the integration of digital technologies such as the Internet of Things (6). It encompasses several digital tools whose objective is to provide digitalized solutions (7). Then comes the use of digital tools and technologies such as robots, artificial intelligence, the Internet of Things, big data, 3D printing, and machine learning. (8)

Some authors describe Industry 4.0 as systems that communicate and cooperate, but also with humans, in order to decentralize decision-making (9).

Industry 4.0 is also known as digitization, which involves replacing humans with machines and digitizing all processes, thus making manufacturing systems and the supply chain intelligent (10).

Several authors, such as (11), have focused their studies on the impact of Industry 4.0 on quality management and the challenges facing a transformation to Quality 4.0, whereas others, such as (12), have focused on data management and solutions based on the two digital tools, deep learning and machine learning. (13) designed a survey to study the application of smart supply chain technologies in Moroccan industry, so (5) in turn studied the state of manufacturing companies, more specifically small and medium enterprises in Germany. This study, using the results of the survey, allowed for a better understanding of digital technologies by managers and the state of advancement in digital.

With the aim of identifying the factors that influence companies to adopt a 4.0 strategy in their practices, we launched a study to make this choice. When there is only one evaluation criterion, choosing influencing factors is obvious, but taking several criteria into account makes things more complicated and complex. Various multi-criteria classification methods have been presented in the literature, but in our case, we're going to focus on the AHP multi-criteria method.

The AHP method, or Analytical Hierarchy Process, was developed by (21) and is one of the best-known and most widely used multi-criteria classification approaches. Its aim is to solve complex multi-criteria decision problems with several alternatives and by applying several criteria simultaneously, according to (22- 23). This method's particularity lies in its ability to structure factors while offering a relatively simple solution to decision-making problems. It uses pairwise comparison questions to obtain a matrix of judgments about the relative preference between each pair of alternatives in relation to each attribute, as well as a matrix of judgments about the relative importance of each pair of attributes. According to (24-25), it offers the possibility of analyzing a problem logically, moving from a higher to a lower level until a simple comparison is obtained for each pair of criteria. Then, we can go back to the top level to make a decision.

The main advantage of the AHP technique is that it offers systematic steps for synthesizing information using a structured hierarchy. According to (26), the hierarchy groups together criteria and sub-criteria, which can facilitate the understanding and simplification of a problem by offering better focus when assigning priorities to criteria and sub-criteria.

3 Methodology

This article presents a field investigation of Industry 4.0 for Moroccan enterprises. The study collected the opinions of industrial managers in companies on the state of the latter's digital transformation.

A group of research professors who had already worked on similar subjects and industry professionals drew up the initial list of questions. We made the selection of the initial list of questions during a brainstorming session, and then we applied a weighted vote.

After several rounds of discussions and corrections, we completed the final questionnaire, comprising 31 questions and covering several aspects, including the level of digitalization of Moroccan companies, the digitalization tools used to date, the main benefits of digital strategy, and the impacts and obstacles of digital tools on the organization.

To select the six influencing factors, we held an online brainstorming meeting with 10 managers from companies that have already adopted a digital strategy. Once a list of factors had been collected, a weighted vote was held to finalize the list of influencing factors for choosing to implement a digital strategy. We then used the multi-criteria method to analyze the results of this section.

A survey approach has been adopted, a survey structured on a website for data collection. It's an online survey and polling platform and software that allows the creation of surveys to which an unlimited number of users can contribute.

We collected a database of companies in Morocco, filtered the companies to remove duplicates, and then decided to focus on large companies and SMEs. To complete this project and obtain consistent and accurate statistics, the questionnaire was sent and distributed to 72 industry professionals. The survey must be completed by people with knowledge and visibility on the digitalization strategy used by their companies.

We then proceeded to contact our target group, sending out emails and, after several reminders, collecting 56 responses, giving us a response rate of 84%. However, we only took into account completed questionnaires, giving us 34 companies that responded in full to the questionnaire, which will be stored for later analysis. The survey responses were collected between December 2022 and July 2023.

Data analysis was carried out using R software and SPSS, and the section dealing with influencing factors was analyzed using the AHP multi-criteria method.

This questionnaire was designed to find out whether companies in Morocco are adopting Industry 4.0 measures and possibly to understand the reasons why companies would be slow to introduce Industry 4.0 into their practices.

This work would also enable us to find out where companies in Morocco stand with 4.0 and what digitization tools they are using.

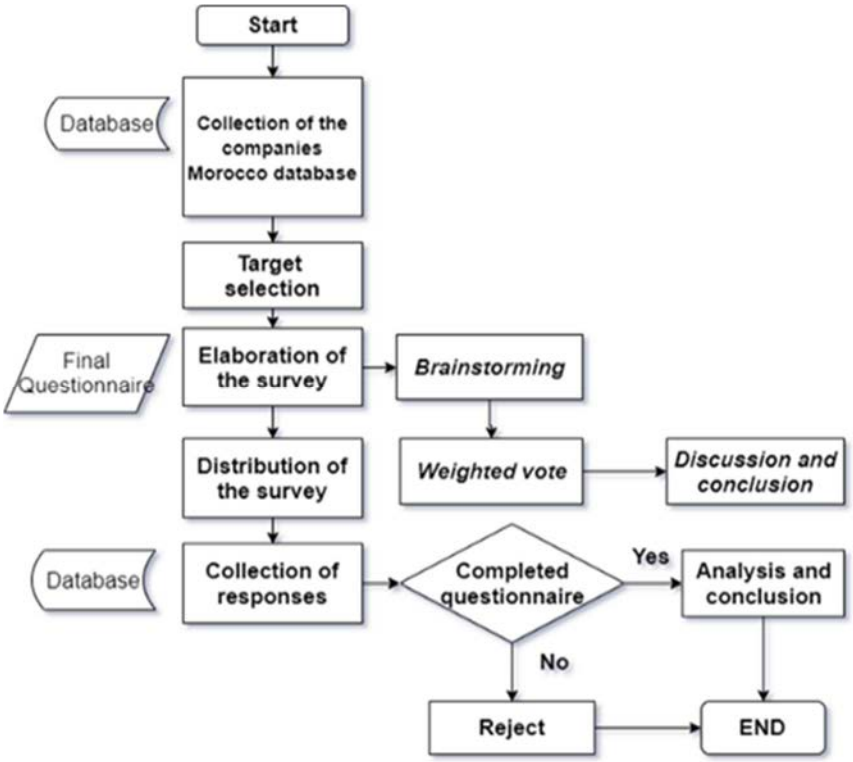

Figure 1 Structure of the survey

4 Results and discussion

This section aims to describe and analyze the questions we asked in our survey.

To ensure reliable results, we have kept the names of the companies confidential. We decided to contact the company managers, as they are the people best suited to answering our survey.

4.1 General analysis

Table 1 contains all the demographic data for the companies surveyed, including their distribution by size, business sector, and business area.

For the breakdown of respondents by company size, the total sample is made up of 34 companies, divided into 58.8% small and medium-sized companies, with the remainder being 41.2% large companies.

With regard to the breakdown by company sector, we decided to diversify the sectors of activity of the companies that took part in our survey and found that 41.2% belonged to the manufacturing industry, 23.5% to the transport and warehousing sector, 14.7% to the trade sector, 11.8% to the automotive and manufacturing industry, and 8.8% to the consultancy sector.

The results of the breakdown by business area show that 26.5% of our population is involved in industrial production, 23.5% in purchasing, logistics, and IT, 14.7% in technical services, and the remaining 11.8% in R&D. We can therefore say that digitization applies to the company's various processes, which shows that all parts of the company are concerned with digitization.

We analyzed the distribution of companies according to sector and size. In Table 2, we found that 43% (n = 6) of the large companies belong to the transport and warehousing sector, 21% (n = 3) to the manufacturing and trade sectors, and 7% (n = 1) to the consulting and automotive sectors.

We found that 55% (n = 11) of SMEs belong to the manufacturing industry sector, 15% (n = 3) to the automotive industry sector, and 10% (n = 2) to the trade, transport, warehousing, and consulting sectors.

We can therefore conclude that digital transformation encompasses all sectors of activity and is not limited to a few.

Table 1 Respondents' descriptive statistics

		Frequency	Percentage
Size of company	Large company	14	41.2
	Small & medium-sized companies	20	58.8
Business sector	Manufacturing Industry	14	41.2
	Trade	5	14.7
	Transport and storage	8	23.5
	Automotive industry	4	11.8
	Consulting	3	8.8
Business Area	Studies, R&D	4	11.8
	Logistics, Purchasing	8	23.5
	Technical services	5	14.7
	Industrial production	9	26.5
	IT	8	23.5

Table 2 Distribution by sector of activity & size of company

		Large company	Small & medium sized companies
Business sector	Manufacturing Industry	21%	55%
	Trade	21%	10%
	Transport and storage	43%	10%
	Automotive industry	7%	15%
	Consulting	7%	10%

4.2 Factors for adopting a digital strategy

We chose 10 expert managers in companies already using a digital strategy, the aim being to involve experts who already apply digital in their jobs in this work, so a brainstorming meeting was held to collect all the experts' opinions and views, and a list of 14 factors was taken into consideration. Given that the number of factors was rather large, and to keep only what was important according to our experts, we used a weighted vote to rank all the factors in order of importance and influence. Finally, a six-factor list was applied to this work. In addition, it is perceived as an effective method for identifying and eliminating imperfections (27).

For the AHP method, we used the following factors:

- ✓ Productivity increase (PI)
- ✓ Cost reduction (CR)
- ✓ Job creation (JC)
- ✓ Improved customer satisfaction (CS)
- ✓ Improved margins (IM)
- ✓ Enhanced data security (DS).

The factors selected above were arranged in a hierarchy based on the AHP technique. We have placed the work objective at the first level of the hierarchy, followed by the evaluation criteria at the next level.

The factors chosen by the experts are used to build the hierarchy for applying the AHP. A group meeting was organized to set up the AHP. Adapting the guidelines of (28-29), we tried to apply the first step of the AHP, which is the construction of comparison matrices for each pair of criteria. Each expert is then asked to make a pairwise comparison between the different factors by constructing a matrix specifying a scale ranging from 1/9 to 9 according to the importance of the parameter (table 3). At this level, the involvement of the 10 managers is critical, as they are in the best position to assess the relative importance of the criteria in pairs.

Table 3 Saaty scale AHP

Numerical value	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values

Equation (1) allows us to calculate the number of pairwise comparisons required for each matrix.

Pairwise comparisons in each matrix (1)

$$= \frac{n(n-1)}{2} \quad (1)$$

n is the number of criteria in the matrix.

To understand this, let's take the case of our study: we've detected six factors that influence the choice of companies to adopt a digital strategy, so n = 6, applying equation (1), 6(6-1)/2 = 15 pairwise comparisons.

Table 4 shows a pairwise comparison of our different criteria. The diagonal elements of the matrix have been assigned the value 1, as aij=1 when i=j.

The matrix that contains all of the criteria coefficients is as follows:

Table 4 AHP starting matrix

Factors	PI	CR	CS	IM	DS	JC
PI	1	2	1/2	1/4	2	3
CR	1/2	1	1/4	1/2	3	3
CS	2	4	1	3	3	5
IM	4	2	1/3	1	2	3
DS	1/2	1/3	1/3	1/2	1	2
JC	1/3	1/3	1/5	1/3	1/2	1

Once the pairwise comparisons had been completed, they were summarized to determine priority. To accomplish this, geometric mean normalization was employed (30). To determine priority, the n elements of each line were multiplied, and the nth root was calculated. The resulting figures were then standardized.

Before calculating the weighted scores, it is essential to test the consistency of pairwise comparisons at the matrix level by calculating the CR consistency ratio using the following equation (2):

$$CR = \frac{CI}{RI} \quad (2)$$

With CI, the coherence index is calculated using the equation below (3):

$$CI = \frac{\lambda max - n}{n-1} \quad (3)$$

with λ max: maximum eigenvalue of each factor in the matrix table and n the matrix size.

RI is the random index developed by SAATY in 1977, as shown in table 5.

Table 5 Random coherence index (SAATY, 1977)

n	1	2	3	4	5	6	7	8
R.I	0	0	0.58	0.90	1.12	1.24	1.32	1.41

After calculation, we find (4):

$$CR = \frac{\frac{\lambda max - n}{n-1}}{RI} = \frac{\frac{6{,}5887-6}{6-1}}{1{,}24} = 0{,}0094 \quad (4)$$

The consistency ratio is well below 0.1, confirming that judgments are consistent at the matrix level. The calculation of the scores for the various factors and their multi-criteria classification are presented in the following table 6.

Based on the AHP multi-criteria method results, the CS factor has the biggest impact on companies' use of digital tools, with a percentage of 35.5%. The IM factor comes in second, with a rate of 22.4%, and then PI with a rate of 15.3%, based on the assigned judgments. Finally, JC with 5.3% rounds out the top five.

Table 6 AHP final matrix

Factors	PI	CR	CS	IM	DS	JC
PI	1	2	1/2	1/4	2	3
CR	1/2	1	1/4	1/2	3	3
CS	2	4	1	3	3	5
IM	4	2	1/3	1	2	3
DS	1/2	1/3	1/3	1/2	1	2
JC	1/3	1/3	1/5	1/3	1/2	1
Normalized weight	0.153	0.131	0.355	0.224	0.086	0.053
RC = 0.094						

4.3 Specific analysis

4.3.1 Axes adopted in the digital transformation

All the participants demonstrated that their companies have a digital strategy and that they are aware of this transformation strategy, and they mentioned that to have a digital strategy, it is necessary to acquire and integrate new knowledge and skills to implement the company's digital transformation.

We presented our stakeholders with a list of axes that the company can adopt as part of its digital transformation strategy, with a scale of 5: Absolutely, partially, not really, not at all, and the company is not concerned. According to the results obtained, we can see that the development of digital innovations and the big data policy are the most used with a rate of 100% of our target, then comes the development of the company's presence on social networks at 85% and the digitalization of sales and distribution networks with a rate of 76%, then we find the adoption of cloud computing offers with a rate of 58% and the use of a smart data policy at 44% of responses (Figure 2).

On the other hand, 14.7% of our population are against the adoption of cloud computing offers as an axis adopted by digital transformation, as well as 11.8% against smart policy data and 8.8% against digitalization of the customer experience.

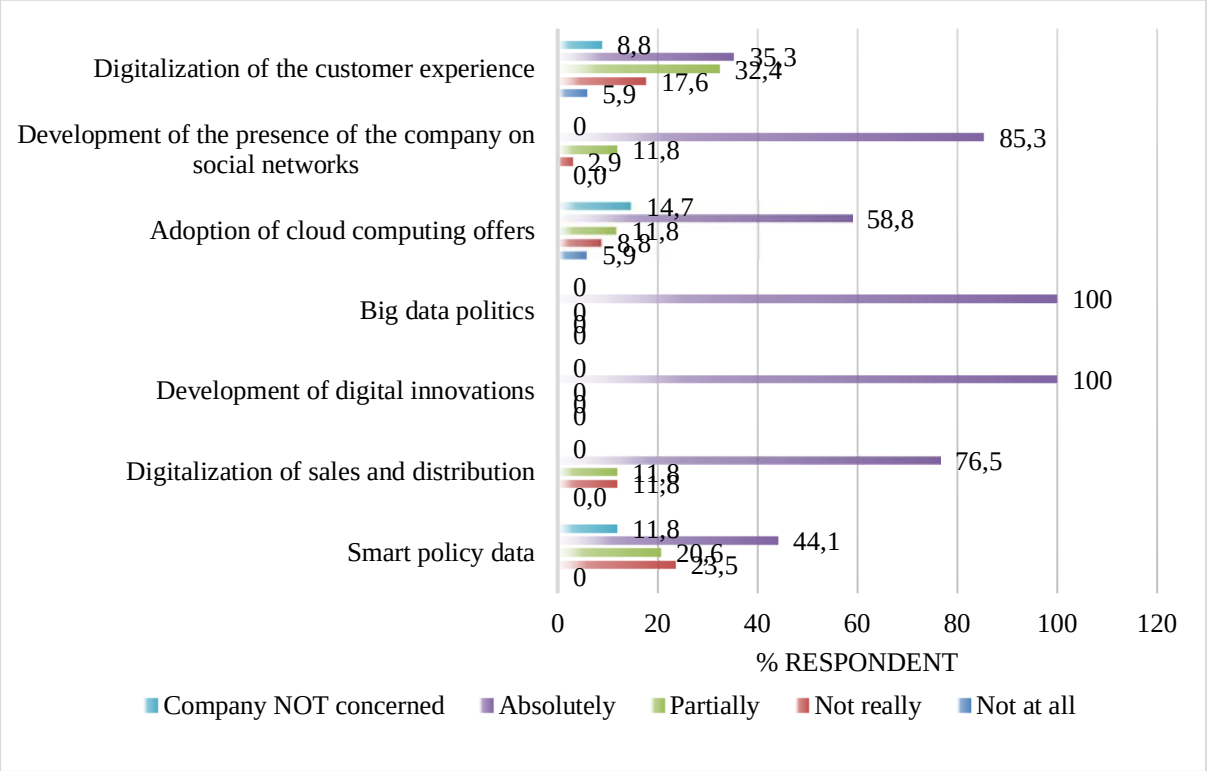

Figure 2 Axes adopted in the digital transformation

4.3.2 The impact of digital transformation & frequency of use of 4.0 tools

Moving on to present the impacts that digital transformation has had, or will have in the future (figure 8), within these companies: 93% see the creation of new jobs as a challenge of digital transformation, 90% for changes in working practices, 87% for the development of employees' technological skills (including training), 72% for strengthening the information systems function, 65% for investment in R&D, and investment in new design and production technologies.

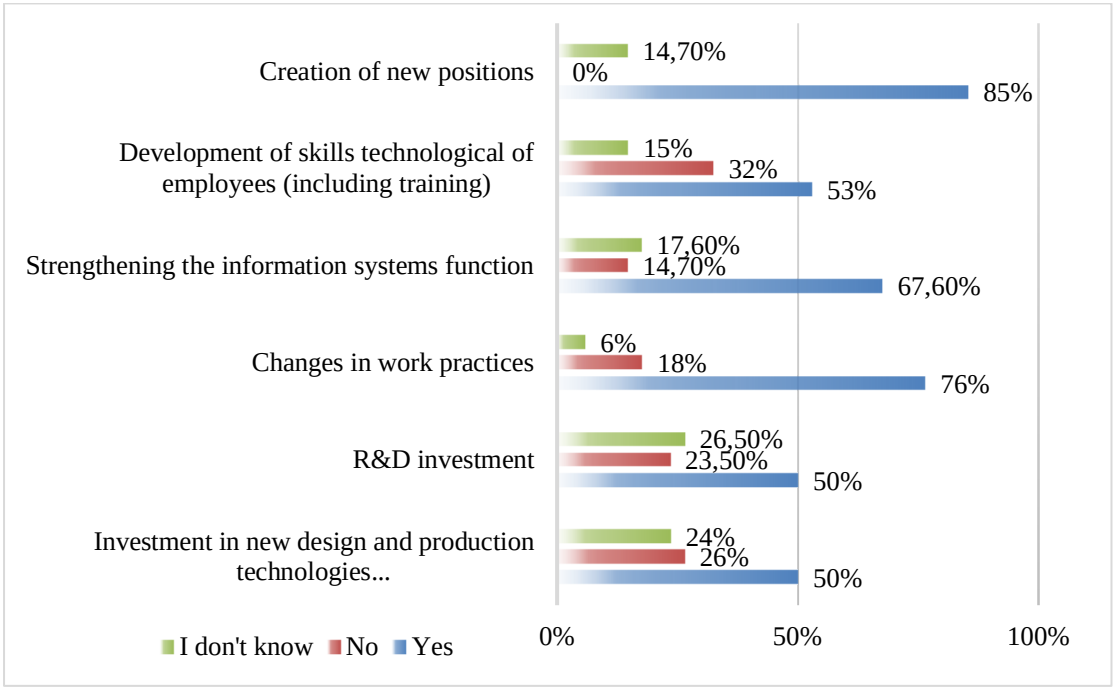

Figure 3 The impact of digital transformation

We presented a set of digitization tools to our respondents to find out what digital tools these companies use, so we found that all participating companies use social media, 31 companies use ERP, 21 with IOT, big data, big data analytics, and BI, 29 use simulation software, 17 exploit e-commerce in their practices, 12 among the target practice artificial intelligence, 15 use CAD/CAM and intelligent supply chains, and 13 employ Production Management Systems (MES). In addition to the use of CRM by 18 companies and 11 for predictive maintenance, we note the absence of several digital tools, namely: crowd, additive manufacturing, cloud computing, M2M, and Cobots. The lack of use of several digitalization tools by these companies shows that we are still in the implementation phase of a few tools to test the feasibility of this transformation.

4.3.3 The benefits and obstacles of digital strategy

Although implementing a digital strategy within companies is costly, it has positive impacts and benefits for the organization. According to the results of this questionnaire, we can say that our entire target group affirms that the transformation has improved image and reputation with customers, as well as customer satisfaction, then 75% of the population confirms as a benefit: improvement in ability to respond to market opportunities and also in the success rate of new products, but on the other hand the remaining 25% partially agree with this statement, then we have the whole target partially agree with the improvement in sales, 50% agree with the improvement in the rate of introduction of new products as a benefit and the remaining 50% partially agree, and towards the end, 75% totally agree with the improvement in ability to respond to market opportunities and in the success rate of new products and 25% partially agree.

After calculating the average, we can deduce that more than 85% of our target audience agrees totally or partially with the various benefits presented in the study.

Table 7 The benefits of digital transformation

	Not at all	Not really	Partially	Absolutely
Improvement margins	8.80%	17.60%	26.50%	47.10%
Improved success rate of new products	5.90%	11.80%	29.40%	52.90%
Improved ability to respond to market opportunities	-	-	38.20%	61.80%
Improved image and reputation with customers	5.90%	17.60%	50%	26.50%
Improved image and reputation with customers	-	11.80%	26.50%	61.80%
Improved customer satisfaction	-	-	41.20%	58.80%
Improvement sales	-	-	-	100%
Average	2.94%	8.40%	30.26%	58.41%

We have now turned to the obstacles that can disrupt digital transformation. Based on our target audience's experience, we found that 25% of our target population strongly agree that the need for a global overhaul of the company's information system is an obstacle to digital transformation, while the remaining 75% partially agree. 25% of our target group still agrees with the complexity of digital transformation projects, the lack of technological skills, and the lack of legal skills, while 25% strongly disagrees with the lack of technological, managerial, and legal skills as obstacles. We can therefore deduce that, when it comes to implementing a digital strategy in a company, several obstacles will stand in the way.

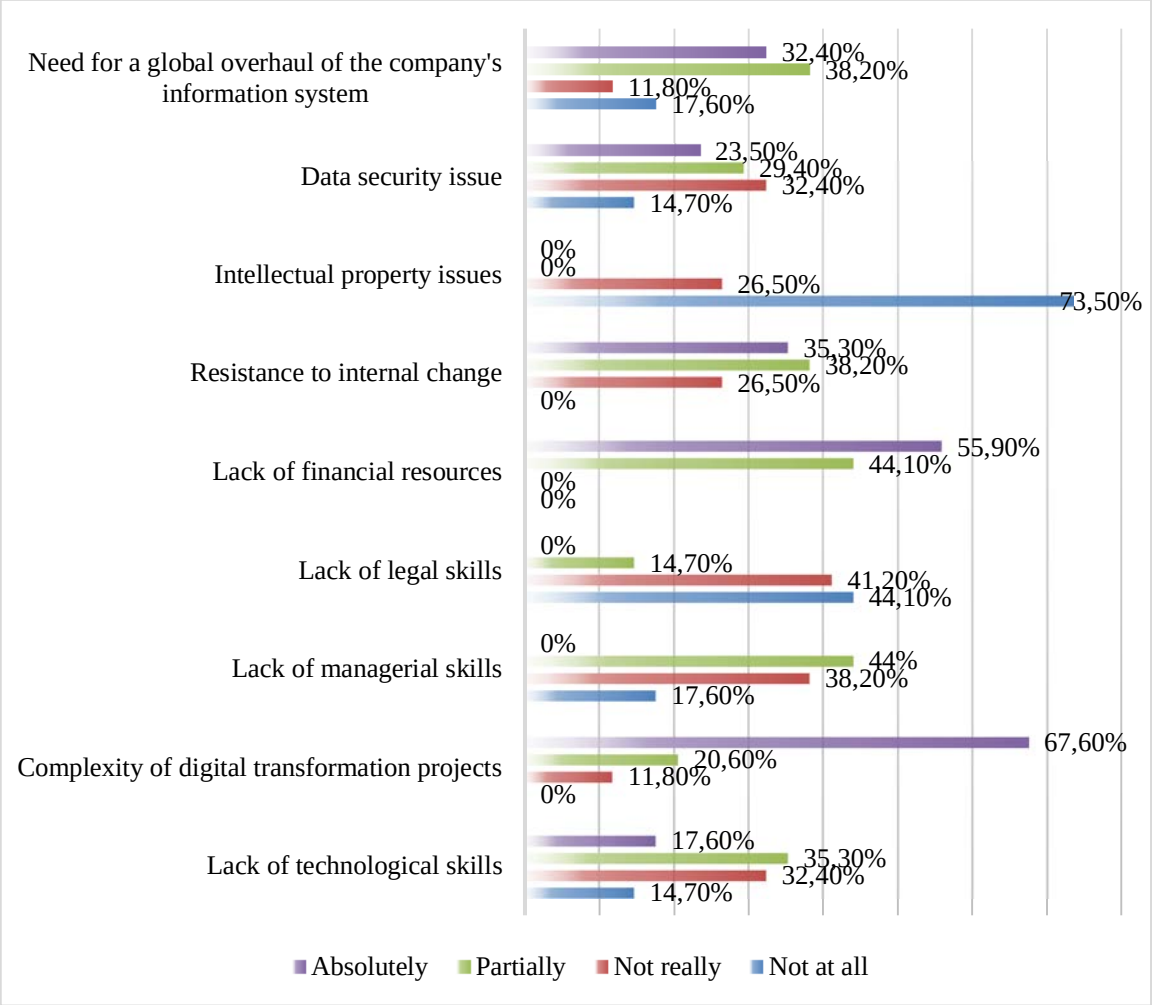

Figure 4 Digital transformation obstacles

4.3.4 Jobs created and Types of training adopted by the digital strategy

As part of the digital transformation of companies, the latter claimed that several new positions have been created. 90% of our target sees that the position of data scientist has been created thanks to digital transformation; 75% sees the creation of the position of chief digital officer and community manager; and on the other hand, all the target sees the non-creation of the position of agile coach, so we can see that digital transformation creates job offers and opportunities.

To implement the company's digital transformation, it is then necessary to acquire new knowledge and skills. According to our respondents, the entire target group has carried out in-house training and online training (e-learning, MOOCs), so 88% of the population has used external training organizations, and 10% has carried out self-instruction.

We found that our population uses daily means of communication even before the implementation of digital transformation, such as email, SMS/MMS, videoconferencing systems, and instant messaging/chat.

During our survey, we focused on digital security, so we devoted several questions to understanding whether these companies are securing the digital tools they have at their disposal. We found that the entire population has a digital policy either implemented or in the process of being implemented, and the person responsible for this digital security policy is the IT department, according to 90% of the target, and the rest is a subsidiary of the company that takes care of it.

5 Conclusions

The results of this survey indicate that Morocco has begun to introduce the basics of Industry 4.0 into its industry practices, including large companies and SMEs, while taking into consideration the various existing sectors.

The results show that, regardless of company size or sector of activity, companies adopt a digital strategy or begin to introduce it into their practices. Our target is aware that to adopt digitalization, it is necessary to acquire new knowledge and skills, which are necessary to succeed in the digitization of processes. These skills must be acquired

either through training organized by the enterprise or even through self-training.

By analyzing the level of use of digital technologies, it appears that most of our population is not taking the full measure of 4.0 technologies, and this is due to the lack of knowledge and overall understanding of the 4.0 concept by our target, which shows that industry 4. 0 in Morocco in its entirety is limited to the use of social networks, e-commerce, software simulation, ERP, and the use of the two digital tools IOT and big data, which then requires investment in the implementation of other digital tools that will help companies win in terms of productivity and financial gains, in addition to the need to develop the knowledge and skills of staff to make better use of emerging technologies and gain mass and continuous benefits from this digital transformation.

For the factors influencing the choice of adoption of the digital strategy, we have found several factors that can influence this choice, except that only six have been implemented as being the most influential, the choice from this list is made taking into account the common strategic objectives among all companies whether their size or their business sectors, namely, the Productivity increase factor because the objective of each company is to increase its productivity to gain in terms of costs and produce more in the same time allocated in advance, the second factor chosen is Cost reduction & Improved margins, each enterprise seeks to minimize its costs and expenditures and maximize its profitability, increase its profit margin, which is more applicable by adopting a digital strategy. Job creation is important because it entails the emergence of new jobs in the working world. Digital experts are in high demand in the labor market. Improved customer satisfaction: as more and more customers have new requirements, they expect to be informed quickly, simply, and in a transparent way. The digitalization of the customer relationship thus enables us to meet all these expectations related to the client relationship. In the end, the factor of enhanced data security remains; it is a very sensitive factor because if enterprises do not take data security seriously, their reputation will be irreversibly degraded in the case of highly media-based attacks, without forgetting that data confidentiality is an important point to control.

Our research has certain limitations that may open the door to future work. As already presented, our study focused on companies from different industrial sectors, and we are well aware that each sector has its own characteristics, which may make future research on each sector separate.

Another important feature is the selection of factors that influence the implementation of a digital strategy. We chose factors using a brainstorming meeting and a weighted vote, so future work can choose factors studied based on a model already existing in the literature.

From the results obtained, we can therefore conclude that the adoption of new technologies necessarily requires the creation of new positions, as well as a total or partial modification of working practices, which then shows that investing only in the implementation of new technologies is not enough to gain a competitive advantage for your company, but you also need to invest in the workforce either by creating new positions or by training existing staff, because the absence of a digital culture within the company and a lack of training and skills leads directly to an unsuccessful transformation.

Digitization, then, is a mandatory and essential transformation step for companies to increase their competitiveness and flexibility in the face of change and competition. Most companies are adopting digital strategies in their practices to increase productivity. In the first instance, creating a connected factory where machines can communicate with each other, reducing risks, and improving product and process yield and quality—not to mention the gains in terms of multi-level cost reduction and improved margins achieved—are all essential factors influencing the choice of companies to implement a digital strategy in their practices.

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Location selection for logistics centre using PROMETHEE method
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Location selection for logistics centre using PROMETHEE method

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Keywords: logistics, PROMETHEE, AHP, automotive industry, location problem.
Abstract: Logistics and distribution centres are essential to the supply chains of many manufacturing and logistics companies. Efficiently locating logistic centres involves thorough search for optimal place, prioritizing proximity to suppliers and minimizing costs. Companies' management often solves the location problem of new halls, mostly to minimise the associated costs. Such a problem is solved in the automotive industry as part of the launch of a new international project. The key factor for the decision of where to locate the logistics centre is the location of the suppliers, since material deliveries generate a large part of the project costs. The aim of this study is to define a methodology for the location of the logistics centre, considering several alternative locations and relevant criteria. The location alternatives and criteria are defined in terms of minimising project costs and sustainability elements. The problem is solved using the multi-criteria decision-making approach. First, the AHP method is used to assign weights to the criteria. Then the PROMETHEE method is applied to find a suitable location for the logistics centre and to perform a thorough sensitivity analysis. The sensitivity analysis is focused on the impact of values of weights on the solution. Consequently, the analysis proves the correctness of the selected alternative. Based on the case study, a general methodology for locating a logistics centre is proposed.

1 Introduction

Finding a location for a logistics centre, distribution centre or warehouse is a crucial logistics issue that is being addressed by many companies and researchers around the world in different fields. These objects are considered as value generators in the flow of products that influence the efficiency of the whole supply chain [1]. The choice of their location is one of the strategic logistics decisions. A logistics strategy that reflects industry and market needs leads to higher competitiveness [2]. The choice of location requires systematic decision-making and forecasting, as its establishment involves high investment costs. By making inappropriate decisions, a company can endanger not only its economic situation, but also its environment and stakeholders [3].

Logistics centres have been part of supply chains since the last century. However, there is no standard methodology and criteria for determining the location of a logistics centre [1]. One of the reasons for this is the individuality of needs and input data, which require different approaches. The content of this paper is a case study in the automotive environment, focusing on the proposal of the logistics centre location for a new international project of a major automotive company. The production of a car requires the handling of a large number of parts and components supplied by a wide range of suppliers. This case study is specific in terms of the need to use intermodal transport. When intermodal transport is used, the same unit (container) is transported by 3 modes of transport - water, rail and road. The availability of the intermodal transport network plays an important role in transport efficiency [4]. The importance of the distance of transport hubs from the logistics centre in relation to the reduction of environmental impacts has been demonstrated in a research paper in [5]. Their research was supported by 8000 scientific articles. Several of these articles were analysed in detail. In addition, the proposed location of the logistics centre should meet the conditions of sustainability. Sustainability includes not only environmental criteria, but also economic and social criteria [6].

Considering the risks involved in the construction of the logistics centre and the magnitude of the problem, it was appropriate to solve the location problem scientifically. There are many approaches to solving the location problem in the literature. However, there is missing standardised methodology that could be applied regardless of the specifics and would be less complicated for companies to use in practice. This could be seen as a research gab.

The aim of the paper is to propose a methodology for the location of a logistics centre that works with the structure of the supply chain (location of suppliers in reference to a case study) and other criteria related to

minimising logistics costs and supporting the sustainable development of the company. A methodology is proposed to explore relevant factors that represent location constraints. It also proposes an appropriate approach to differentiate their importance.

In order to achieve the objectives given, it was first necessary to consider the distribution of suppliers in the logistics network when designing the methodology. The reason why their placement is so important is that material supply generates the majority of the total project costs. Minimising material supply costs was achieved by using the gravity centre method. However, other relevant criteria also influence the decision-making process. The individual criteria were selected in relation to the pillars of sustainability. Due to the existence of several criteria, the gravity centre method was followed by multi-criteria decision making (MCDM) methods. Criteria weights were calculated using the Analytic Hierarchy Process (AHP) method [7]. The defined alternatives were ranked using the Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE) [8]. The combination of these two MCDM methods has been already applied by [9] and [10].

Section 2 contains the theoretical background of all used methods. In Section 3, the methods are applied in the case study. Section 4 presents the results and provides recommendations.

2 Theoretical background

This section briefly recalls three mathematical methods used in this paper. Namely, the gravity centre method for finding the location, the AHP method (only the part of the method that is necessary to calculate the weights of the criteria) and the PROMETHEE methods for ranking the alternatives. In all three cases, the reasons for the choice of method are also provided.

2.1 Gravity centre method

This simulation method deals with the problem of planning a logistics network in which a transport flow is carried out from an initial location to a final location. The method is based on the minimisation of transport costs, taking into account the distance and volume of goods transported between current facilities. The found gravity centre is considered as the optimal point of the logistics node in the system of objects. The method does not take into account the costs generated by the geographical location of the facility (e.g., land use charges, construction costs, labour costs). Nor does it take into account the future benefits of the facility. This mathematical technique is often used in practice, for example, to find the ideal location for a distribution centre or warehouse [11].

The coordinates of the gravity centre, determining the appropriate location of the device, are calculated according to the formula (1) and (2). The w_i represents the volume of supply or demand in considered location i $(i = 1,2, \dots, n)$, which corresponds to the coordinates d_{ix} and d_{iy} [12].

$$x = \frac{\sum_{i=1}^{n} d_{ix} w_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

$$y = \frac{\sum_{i=1}^{n} d_{iy} w_i}{\sum_{i=1}^{n} w_i}. \tag{2}$$

In the literature, transport costs are often included in the centre of gravity model through a transport rate [13]. This method is applied to obtain the values of one of the important criteria in the case study.

2.2 AHP method – deriving the weights

The AHP algorithm can be split into two phases. In the first phase, the weights of criteria w_j are found. In the second phase, the utility of alternatives is calculated. Since the method is used just to derive the weights in this paper, the second phase will not be described here. An interested reader can look at Saaty [14]. The AHP method is based on the hierarchical structure of the problem, and the hierarchical structure of the criteria. Namely, each criterion C_i out of k evaluation criteria are split into g_i sub-criteria C_{ij}. Then, the criteria and each group of sub-criteria are evaluated one by one using the Saaty's matrix. This matrix provides pair-wise preferences s_{ij} using the Saaty's scale (1 = indifference, 2, 3, …, 9 = increasing preferences), for more details [14]. There are more ways how to derive the priorities from the Saaty's scale. The geometric mean method [12] is one of them, see (3):

$$w_i^L = \frac{\left(\prod_{j=1}^{k} s_{ij}\right)^{1/k}}{\sum_{i=1}^{k}\left(\prod_{j=1}^{k} s_{ij}\right)^{1/k}}, \forall i, \tag{3}$$

where s_{ij} stands for the element of the Saaty's matrix.

These priorities are called local weights and denoted as w_j^L (in case of criteria) and w_{ji}^L (in case of sub-criteria of the criterion i). The final (global) weights w_{ji}^G are calculated for each sub-criterion in the group i using (4). In total, $\sum_{i=1}^{k} g_i = K$ global weights are calculated. Since the hierarchical structure is not relevant for the rest of the algorithm, we can consider the problem as an MCDM problem with flat (single level) structure of K criteria.

$$w_{ji}^G = w_{ji}^L w_i, \forall i, j \tag{4}$$

The quality of each matrix should be checked using Consistency Ratio CR, which can be calculated from (5). If $CR < 0.1$, then the quality of the matrix is good enough. Otherwise, the evaluation should be adjusted.

$$CR = \frac{\lambda^{\max} - k}{(k-1)RI} \tag{5}$$

where λ^{max} is the greatest real-valued eigenvalue of the

Saaty's matrix, k represents the size of the Saaty's matrix and RI is the random index (tabularized value dependent on k, see Saaty [14].

2.3 PROMETHEE method

PROMETHEE ranking method has been introduced by [15] almost 40 years ago. Since that time, its popularity grows for many reasons: (a) it is simple and well traceable; (b) it can handle all data types without the necessity of uncomfortable transformation; (c) it is well supported with available software, providing attractive graphical outputs; (d) it allows performance profiles of alternatives for the analysis, which make understanding of the solved problem easier.

The cornerstone of PROMETHEE ranking is a preference function, which assigns the so-called preference degree $P_i(x_j, x_l) \in [0; 1]$ to each pair of alternatives $(\forall x_j, x_l \in \mho)$ with respect to each criterion $i \in \varkappa$, where $\mho$ ($|\mho| = n$) and $\varkappa$ ($|\varkappa| = k$) stands for the set of alternatives and criteria, respectively. The preference degree is assigned based on the difference in values of the compared alternatives in terms of the given criterion. A decision-maker can choose different shape of the preference function with different parameters for each criterion. [15] introduced 6 predefined shapes of the preference functions. By far, when looking at the published applications, see the review article [16], the most widely used shape is the linear one, with the indifference threshold q and preference threshold p (see Figure 1). After comparing all pairs of alternatives with respect to all criteria, the positive and negative flows of the j-th alternative are calculated as follows (6), (7):

$$\phi^+(x_j) = \frac{\sum_{l \neq j} \sum_{i=1}^{k} w_i \, P_i(x_j, x_l)}{n-1}, \tag{6}$$

$$\phi^-(x_j) = \frac{\sum_{l \neq j} \sum_{i=1}^{k} w_i \, P_i(x_l, x_j)}{n-1}, \tag{7}$$

where w_i stands for the weight of the i-th criterion reflecting its relative importance among the criteria.

The positive flow $\phi^+(x_j)$ expresses to what extent the alternative x_j performs on average better than other alternatives. The other way around, the negative flow $\phi^-(x_j)$ says to what extent the alternative x_j performs on average worse than other alternatives. The partial ranking using PROMETHEE reveals the preference of x_j over x_l if $\phi^+(x_j) \geq \phi^+(x_l) \wedge \phi^-(x_j) \leq \phi^-(x_l)$ (excluding the case when both pairs of flows are equal, revealing the equivalence of both alternatives). Otherwise, the pair of alternatives is incomparable using the partial PROMETHEE ranking (too much controversy in their profiles exists). If one requires the complete order on $\mho$, the complete ranking, using the net flows can be used instead (the grater the net flow, the better the alternative is) (8):

$$\phi(x_j) = \phi^+(x_j) - \phi^-(x_j). \tag{8}$$

To explore the modelled system into details, the partial flows can be calculated for each criterion separately (without adding them together), resulting in the structure of the flows and profiles of the given alternatives.

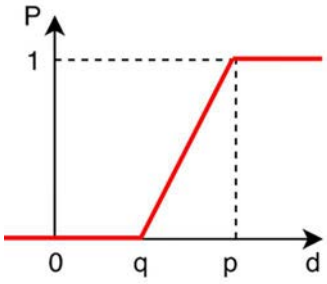

Figure 1 Linear shape of the preference function [16]

3 The case study

The case study focuses on the practical application of the chosen methods to find a suitable location for a logistics centre to be used for a new overseas project of a company operating in the automotive industry. The company manufactures a product consisting of a large number of different parts sourced from 514 suppliers in 26 countries. 96% of the suppliers are located in Europe. Of these, 80% are concentrated in Central Europe. The remaining 4% of suppliers are located outside Europe. The distribution of suppliers is shown in Figure 2.

Figure 2 Location of suppliers

3.1 Application of the gravity centre method

Supplier distribution is a key issue for the company. Material supply is a significant part of project costs. This observation leads to the choice of the gravity centre method, which makes it possible to locate the facilities in a way that minimises transport costs. However, minimising transport costs is only one of several criteria taken into account when searching for a suitable location

for a logistics centre. The gravity centre method can be applied by knowing the GPS coordinates of the suppliers and the assumed annual volumes of material (in m^3 /year) that the suppliers will transport to the destination. Initially, the location of the logistics centre was searched only within the Czech Republic. Then the method was extended to the whole world, depending on the location of the suppliers and their future volumes provided to the project. There are several reasons why the gravity centre method was initially applied only within the Czech Republic. Based on the analysis of the input data, it was found that 74.9% of the annual material volumes are delivered by suppliers from the Czech Republic. Logically, it would be convenient to locate the logistics centre in the Czech Republic, especially in order to save transport costs. For these reasons, the company preferred to locate the logistics centre in the country. Another reason is the possibility of using the coordinate system of the Unified Trigonometric Cadastral Network (referred to as S-JTSK) to find the coordinates, which are essential data in the gravity centre method [12]. Its advantage is the display of the mathematical orientation of the coordinate axes. Working with S-JTSK allows more accurate data to be obtained than with manual coordinates, which must then be used to apply the method to global suppliers.

Based on the formula for calculating the gravity centre [12], the resulting GPS coordinates are [1045993.53, 651168.13]. By specifying the coordinates in S-JTSK, it was found that the coordinates correspond to an uninhabited area in Lhota pod Libčany (Královehradecký region).

In order to determine the appropriate location of the logistics centre based on the distribution of global suppliers, their selection is limited to suppliers that provide at least 100 m^3/year, to ensure data quality and relativity. This condition is met by 152 out of 514 suppliers. For the application of the centre of gravity centre method, the map with a coordinate system is used to determine the location of each supplier. The corresponding formula [12] is used to calculate the resulting gravity centre coordinates [143, 106]. The location found is a town - Nymburk in the Czech Republic (Central Bohemia region). This result confirms the suitability of the location of a logistics centre in the Czech Republic. The resulting location of the centre of gravity is only indicative. The centre of gravity method does not take into account whether the location found will be inhabited or uninhabited. It also does not take into account whether there are facilities in the vicinity that meet the requirements. The gravity centre method should not be used as the main decision-making tool. In the real world, the location should be considered from multiple perspectives and criteria. Therefore, in this case study, two methods of multi-criteria decision making were applied together.

3.2 Application of MCDM methods

For the location of the logistics centre, not only variants defined by the gravity centre method are considered. The company selected 4 other locations that would be appropriate for economic, distance or other reasons. This resulted in 6 alternatives that were compared using multi-criteria decision making. The criteria are chosen to meet the needs of the company and the principles of sustainability in relation to the organisation and society. The first step is to select and weight the evaluation criteria. Since it is natural to find a hierarchical structure of the criteria, the AHP method is used for the evaluation. In the second step, the weights obtained are used to rank the alternatives using the PROMETHEE method.

3.2.1 Evaluation criteria and their evaluation using AHP method

The criteria are divided into three groups - distance, economic and infrastructure (see Figure 3). In [17], PROMETHEE II is used for selection of facility location considering 8 criteria. Similarly, among the criteria, the authors used labour force and traffic intensity.

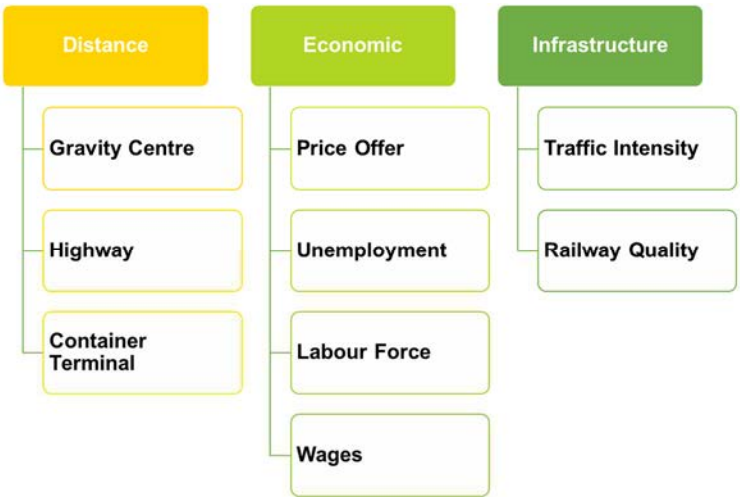

Figure 3 Defined criteria

In addition to the distance from the gravity centre, the distance to the container terminal and the nearest highway entrance were also included in the distance criteria. The distance to the gravity centre is important because it provides a clue, where should be located the facility in order to reduce input costs of the project that are generated by the delivery of materials from suppliers. Moreover, the amount of total logistics costs and emission will be affected by the necessary transport of containers with material from the logistics centre to the chosen container terminal. Therefore, the distance from the gravity centre and the container terminal is directly related to the economic pillar of sustainability by taking into account the minimising transport costs. It is also related to the environmental pillar of sustainability. As a result of minimizing transport costs, the environmental impact of transport will be reduced. The distance to the nearest highway entrances has been included to estimate the quality of the serviceability of the potential logistics centre's accessibility by road, which will be used frequently during the project.

One of the most important criteria are the price offers from potential logistics centre providers, which have a significant impact on the future performance of the company. Price offers are closely related to the economic principle of sustainable development of the company. Similarly, average wages in the location under consideration also have a relevant impact on the future economic situation of the company. The economic criteria also include unemployment and the level of the labour force according to the region to which the location belongs. Unemployment and the level of the labour force are important to the company in relation to the ability of the location to provide sufficient staff. The labour force includes all persons aged 15+ years who fulfil the requirements to be classified as employed or unemployed. The Czech Republic currently faces low unemployment and a shortage of skilled labour [18]. This may represent a risk to the company. In terms of these criteria, it is appropriate to locate the facility in a location with higher unemployment and labour force levels. These criteria can be considered as an instrument to achieve social development in the area where the logistics centre will be located.

The infrastructure in the area is assessed on the basis of traffic intensity and the railway quality. The railway quality represents the coverage of the rail network. Both criteria are also related to the quality of serviceability of the future logistics centre, which will receive large volumes of material deliveries at short intervals. The logistics centre will contribute to an increase in road traffic density, which will have a negative impact on living conditions in the area. Time also plays a role in the delivery of materials to the logistics centre. Delays in deliveries due to traffic density can cause process problems. Therefore, it is advisable to look for areas with lower traffic density from a logistical and environmental point of view. The quality of the rail network is considered aspect due to the potential to use the rail network instead of road transport for materials deliveries from the logistics centre in the future. The use of rail transport would reduce the carbon burden from transport. At the same time, transport costs would be reduced.

The choice of these criteria ensures that the proposed location of the logistics centre links the basic principles of sustainable development. Furthermore, it can ensure efficiency. The criteria form a logical tree structure, which allows to use the AHP method, see Sec. 2.2. First, the local weights, and then the global weights of the criteria have been calculated. The calculation of the weights was based on expert judgement. The results are shown in Table 1.

Table 1 AHP results

Main class	Distance			Economic				Infrastructure	
Local weights	0.540			0.297				0.163	
Criteria	Gravity Centre	Highway	Container Terminal	Price Offer	Unemployment	Labour Force	Wages	Traffic Intensity	Railway Quality
Label	C1	C2	C3	C4	C5	C6	C7	C8	C9
Local weights	0.648	0.122	0.230	0.599	0.104	0.078	0.220	0.800	0.200
Global weights	0.350	0.066	0.124	0.178	0.031	0.023	0.065	0.131	0.033

3.2.2 Evaluation of locations using PROMETHEE method

The PROMETHEE method was used to rank the 6 defined alternatives. These alternatives were compared in the Visual PROMETHEE software. The input data are summarized in Table 2, which also includes the weights obtained by the AHP method. Lhota pod Libčany, determined by applying the gravity centre method, was replaced by the regional city of Hradec Králové, which is 10 km away from the village. The reason was lack of data for some of the criteria. All distances in Table 2 are given in kilometres. The economic criteria - the unemployment rate [%], the level of the labour force [number of people] and the average wages [CZK] are related to the regions to which the area belongs. This information comes from the Czech Statistical Office. The price offer is evaluated with a point estimate in the interval from 1 to 10. The evaluation is carried out by experts from the selected company. In the

case of infrastructure, the information on the intensity of local traffic [millions] also refers to the region and comes from data of the Road and Highway Directorate of the Czech Republic (referred to as ŘSD ČR). The railway quality is evaluated subjectively on a point scale from 1 to 10. The Railway Administration portal was used as the basis for the scoring. The railway quality was evaluated according to the number of lines for cargo transport and the existence of a container terminal, including its suitability for foreign dispatch. A negligibility value was determined according to the values obtained. The preferred function was defined as linear for all the criteria (see Figure 1) with the indifference threshold q determined expertly, and the preference threshold p set equal to the variation range of all alternatives (that brings the highest distinguishing power among alternatives).

Table 2 Decision matrix and parameters of preference functions

	Distance			Economic				Infrastructure	
Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9
Hradec Králové	13	10	120	4	3.32	277717	36912	3.656	4
Kvasiny	60	40	46	7	3.32	277717	36912	3.656	2
Pardubice	22	25	153	1	3.08	265515	34823	3.176	6
Paskov	265	3	2.5	3	5.20	591399	35599	6.645	8
Nymburk	0.5	20	53	4	3.37	758515	39716	10.082	3
Mladá Boleslav	40	0.5	50	5	3.37	758515	39716	10.082	5
MIN/MAX	MIN	MIN	MIN	MAX	MAX	MAX	MIN	MIN	MAX
Weight	35.00	6.60	12.40	17.78	3.09	2.30	6.53	13.10	3.30
Preference Fn.	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear	Linear
Indifference threshold	10	2.0	8	0	0.10	50000	500	0.100	0
Preference threshold	264	39	150	6	2.12	500000	4900	6.900	6

4 Results and discussion

This chapter contains the results of the PROMETHEE methodology. The results are examined on the basis of the net flows and the main visual tools of PROMETHEE. The quality of the results is verified through sensitivity analysis. The aim of the discussion and recommendations section is to provide a guide to the methodology including the benefits and barriers of applying the method.

4.1 Results

Using the PROMETHEE method, the alternatives were ranked according to the value of phi (see Table 3). Kvasiny was evaluated as the best alternative. The value of ϕ was based on the difference between positive and negative flows. The positive flow ϕ^+ indicates how much better a given variant is than the others. On the other hand, the negative flow ϕ^- indicates how much worse a given variant is than the others. How strong its weaknesses are.

Table 3 Ranking of alternatives

Rank	Location	ϕ	ϕ^+	ϕ^-
1	Kvasiny	0.1327	0.2630	0.1303
2	Hradec Králové	0.0906	0.2042	0.1136
3	Mladá Boleslav	0.0194	0.1880	0.1686
4	Nymburk	-0.0186	0.1692	0.1879
5	Pardubice	-0.0375	0.1942	0.2317
6	Paskov	-0.1866	0.2127	0.3994

Figure 4 displays the positive flows (advantages) and negative flows (disadvantages) of each option graphically. The positive flows are displayed using bars above the axis. On the other hand, the negative flows are shown below the axis. The greater the area of the bar represents the greater flow (and thus, either greater advantage or disadvantage). As Figure 4 shows, the main strength of Kvasiny is the price offer. However, its major weakness is distance to the highway entrance, which is not considered a significant factor.

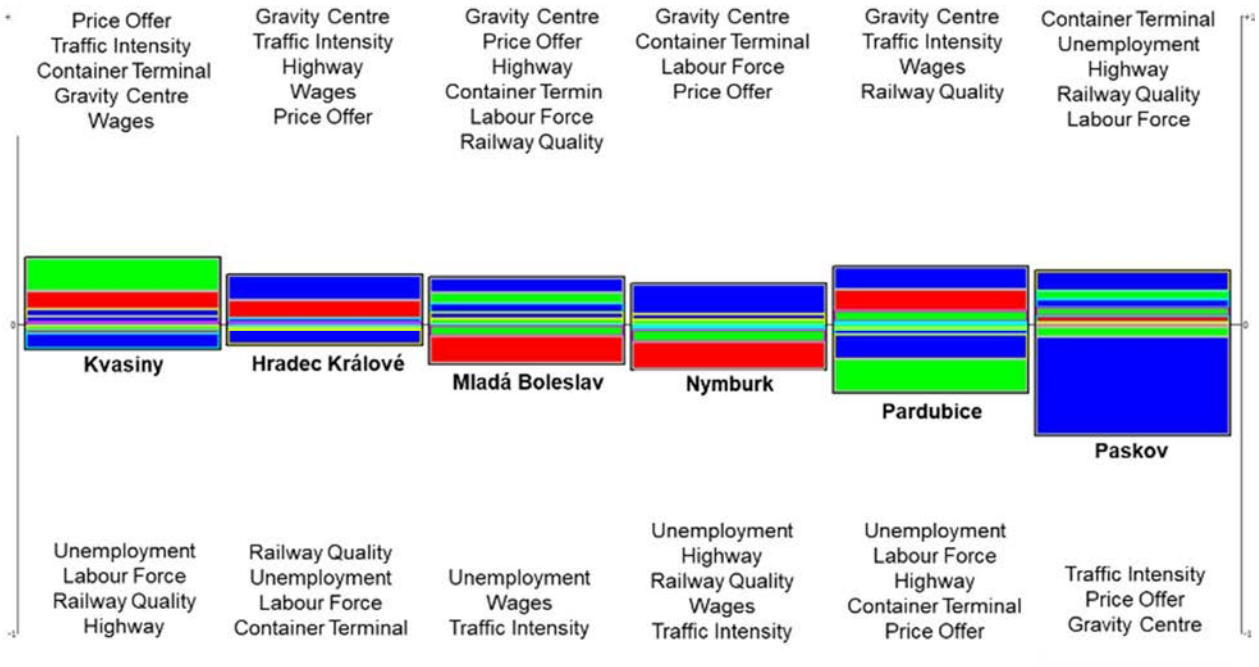

Figure 4 PROMETHEE Rainbow created in Visual PROMETHEE Software

Through Figure 5 it was discovered that there is no connection between Kvasiny and Hradec Králové. These alternatives are not comparable to each other. Kvasiny is the best alternative only in terms of net flows $\phi^+$and ϕ^-.

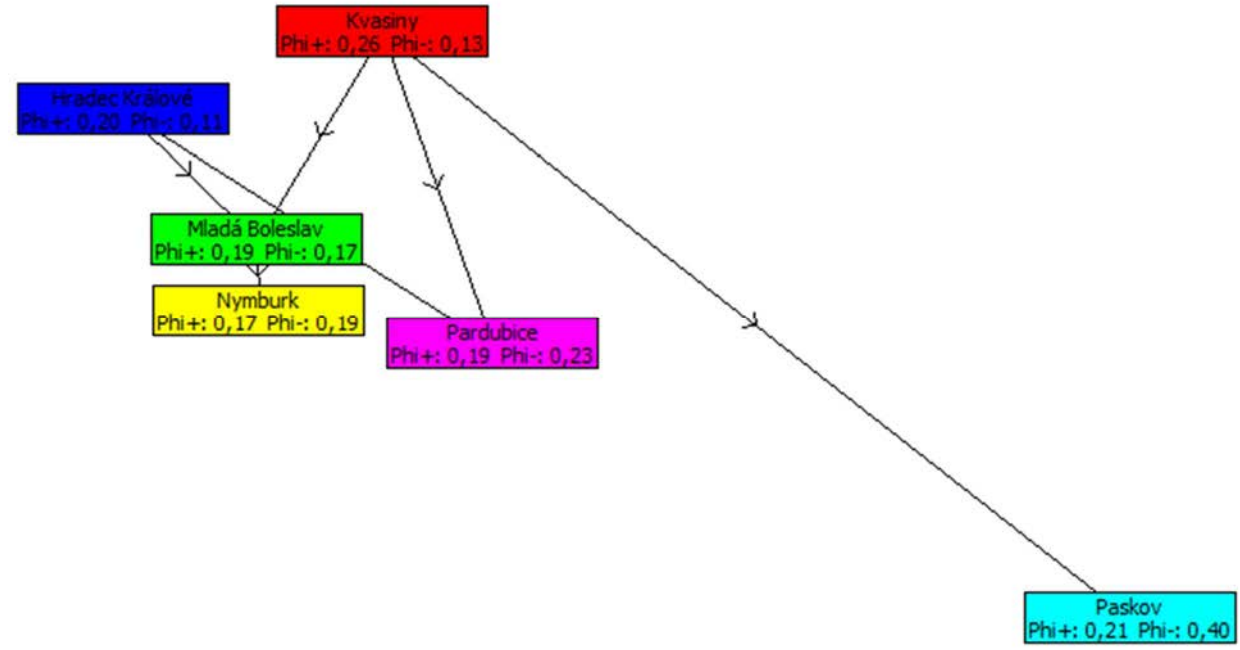

Figure 5 PROMETHEE Network created in Visual PROMETHEE Software

4.2 Sensitivity analysis

The sensitivity analysis is focused on the impact of values of weights on the solution. For this purpose, the tool called "Visual stability intervals" available in Visual PROMETHEE was used. This tool finds an interval for each weight $[LB.RB]$ within which the ranking does not change. Naturally the wider interval, the more stable solution obtained, see Table 4. In the same table, the values by which the current weights would have to be increased/decreased $\uparrow w_i/\downarrow w_i$ are provided together with the swaps of alternatives which would occur the first when exceeding the bounds.

Table 4 Sensitivity analysis of results

	C1	C2	C3	C4	C5	C6	C7	C8	C9
LB	0.248	0	0.103	0.151	0	0.007	0	0.072	0
RB	0.475	0.107	0.224	0.394	0.141	0.081	0.081	0.144	0.063
$\uparrow w_i$	0.125	0.037	0.104	0.214	0.111	0.061	0.011	0.014	0.033
↑swap	HK-KV	HK-KV	PE-PV	PE-PV	PE-PV	HK-MB	PE-NY	PE-NY	PE-NY
$\downarrow w_i$	0.103	-	0.018	0.029	-	0.013	-	0.058	-
↓swap	PE-PV	-	PE-NY	PE-NY	-	PE-NY	-	HK-MB	-

It can be seen that there are 4 criteria, which if they were removed from the model, the final ranking would have persisted (C2 Highway, C5 Unemployment, C7 Wages, C8 Railway quality). A change of the winner happened only in case of two criteria (C1 Gravity centre and C2 Highway). In both cases, Hradec Králové would replace Kvasiny. However, this swap would happen after the change of the weight of Gravity centre by more than 0.1 and such change would mean extreme revolution in preferences. Therefore, the most noteworthy possible change of the winning alternative would happen when the weight of Highway increases at least by 0.037. Nevertheless, the current solution can be considered very stable with respect to changes in weights.

The last analysis explores the role of the weights in general. In other words, how much the ranking changes if all 9 criteria are considered equally important. Surprisingly, complete reshuffle of the final net flows would happen. Namely, the current winner (Kvasiny) would become by far the worst. On the other hand, the current worst solution (Paskov) would become a new best option. This shows how much important is to distinguish different weights for criteria in the solved model.

Based on the results it is apparent that the only two locations which can be considered the best (compromise) ones are Kvasiny and Hradec Králové. Fig. 4 shows that the greatest advantage of Kvasiny is its good performance in price offer. It can be shown that if the price offer of Hradec Králové improves at least to the level of Mladá Boleslav, the net flow of Hradec Králové outperforms the net flow of Kvasiny (and Hradec would become the best option in terms of the partial PROMETHEE ranking. see Sec. 3.2). In case that the price offer of Hradec Králové improves at least to the same level as Kvasiny. Hradec Králové would outperform Kvasiny even in terms of the complete PROMETHEE ranking and the final recommendation would be unambiguous. The other way around if Kvasiny should be evaluated as the best location in terms of complete ranking due to the change in the price offer, then the current Kvasiny price offer would have to be improved to the best possible rating, i.e., 10.

4.3 Methodology and recommendation

The methodology presented in Figure 6 was developed by generalising the case study. The main step of the methodology is to define the objective of the logistics centre. Subsequently, data on the distribution of supply chain subjects are collected. In the case study, these are parts suppliers. Based on the required data about the subjects, the center of gravity method is applied. Through the centre of gravity method, the location that minimizes the transportation cost with respect to the selected subjects is found. This step is followed by defining other considered location alternatives. An essential part of the process is to define all relevant criteria for site selection that will minimise costs and support the company's objectives. The AHP method is used to determine the weights of the criteria. The ranking of alternatives is determined using the PROMETHEE method. The application of this method is followed by a sensitivity analysis to verify the predictive ability of the result. If the result shows to be very sensitive to the change in weights, a revision of the AHP method is required. If the result is judged to be sufficiently stable, the selected site is verified and validated. If there are doubts about the correctness of the result with respect to the specified criteria, the AHP method and the following steps need to be revised again. In the case, the resulting alternative location is considered suitable, real implementation in practice can take place.

The proposed methodology is suitable for those who intend to find a facility location that minimises logistics costs and supports sustainable business development. It is based on methods that can be adapted to different user needs. At the same time, it is versatile enough to be applied to different projects. Moreover, at the same time, it is designed to be easier to implement in the real world of business. This is achieved by combining the gravity centre method with two multi-criteria decision-making methods – AHP and PROMETHEE.

In order to use the centre of gravity method, it is necessary to know the location of the unit in relation to which the facility is located, the amount of material it supplies, its demand or other quantitative indicators. It should be noted that this mathematical and graphical method provides a location that is only indicative. It is important to work with it further. The gravity centre method should be only one of the methods used to decide on the location of the facility. The result is obtained by a weighted arithmetic average, so it is important to be aware of outliers in the form of supplier locations that are more distant than others. For example, if our key suppliers are located overseas, we should use the coordinates of the port to which the material is delivered. This can reduce the number of outliers that distort the result.

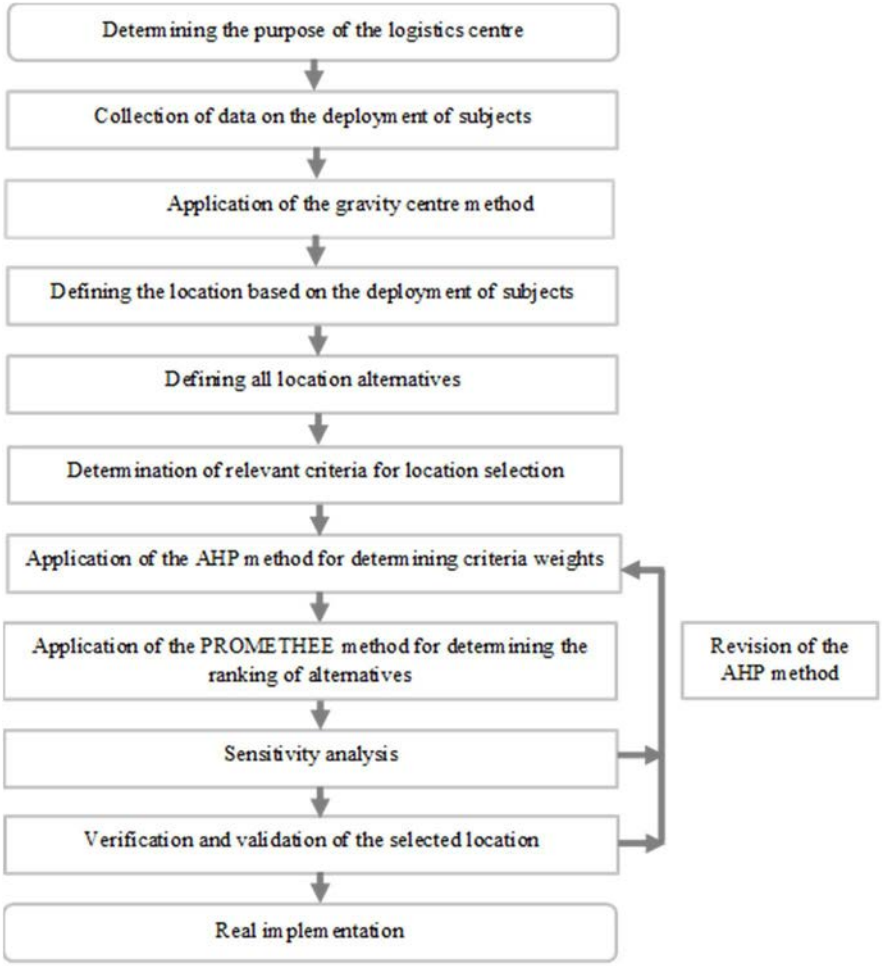

Figure 6 The proposed methodology

A prerequisite for the application of AHP and PROMETHEE methods is the ability to identify the relevant criteria and their weights. The hybrid combination of the AHP and PROMETHEE method provides several advantages for a decision-maker discovered already, e.g., by Taha and Rostam [9]. First, the AHP is invincible for structuring of criteria to the hierarchy that helps to handle more criteria in a single problem and potentially understand the problem better. Second, the PROMETHEE method (supported by free software) brings not only the ranking of the alternatives, but its deeper analysis through the structure of the resulting flows and easy sensitivity analysis too. Third if the ranking of two alternatives is in fact not so clear due to the controversial performance values and their completely different performance profile the PROMETHEE partial ranking reveals this fact and evaluates the given pair of alternatives as mutually incomparable.

Through the defined criteria, the methodology allows for the integration of multiple perspectives that can be used to examine the location of the facility from the perspective of the individual needs of the selected company. At the same time, in this case study, the criteria are designed to ensure that the individual needs of the organisation are consistent with the pillars of sustainability. The selected criteria are not a dogma, but a recommendation. The selection of criteria should be approached according to priorities. In particular, the criteria categorised under distance and infrastructure should always be adapted according to the organisation's material flow structure. The group of criteria could be extended to include. For example, the technological specification (capacity, level of technology, etc.) of the logistics centres in the locations under consideration.

5 Conclusions

This paper dealt with the design of a methodology for finding a suitable location for a logistics centre. The intention was to propose a missing methodology that would complete the research gap in terms of universality and practicality. The methodology was designed with the requirement to be able to work with the material flow structure in order to minimise logistics costs as the logistics centre has a significant impact on its efficiency. The gravity centre method was chosen for this purpose. This method can be applied universally to any supplier or

customer structure. The method was followed by multi-criteria decision-making methods - AHP and PROMETHEE, which allow location alternatives to be examined from several perspectives. The chosen methods were practically applied in the case study. The case study focused on the design of a suitable location for a logistics centre for a new overseas project of a company operating in the automotive industry. The logistics centre will be used to consolidate materials from suppliers and then ship the consolidated shipment to the foreign plant. The supplier network was mapped using data analysis. The distribution of the supplier network was considered using the gravity centre method. Due to the intention to locate the centre domestically and the possibility to use S-JTSK to refine the result. the gravity centre method was first applied within the Czech suppliers. Subsequently, data from other global suppliers providing at least 100 m^3/year were used for its application. The resultant was Lhota pod Libčany in the work with Czech suppliers. In the case of applying the method within the world suppliers, the resulting gravity centre was located near Nymburk using manual coordinates. The result of the gravity centre method, combined with data from global suppliers, confirmed the suitability of locating the logistics centre in the Czech Republic. The defined locations became part of the 6 alternatives examined using multi-criteria decision-making methods. The alternatives were evaluated on the basis of 3 groups of criteria.

The criteria were selected taking into account the needs of the organisation and the pillars of sustainability. The weights of each criterion, which form a logical tree structure, were obtained using the AHP method. One of the main objectives of the company's logistics was to minimise transport costs. Transport costs represent a high proportion of the total project costs. For this reason, distance from the centre of gravity was given the highest weight. The second most important criterion was the price offers received from the logistics centre providers. The PROMETHEE method was used to rank the alternatives. According to the value of net flows, Kvasiny was determined to be the most suitable location. Based on the sensitivity analysis, the result was found to be stable with respect to the change of weights. However, if the criteria were equally important, Paskov would be the "winner" and Kvasiny the "loser". The sensitivity analysis showed that the compromise alternative for Kvasiny is Hradec Králové. The results of the PROMETHEE methods show that these alternatives are in fact incomparable.

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Production and logistics 4.0 in the food industry in the Czech Republic
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Production and logistics 4.0 in the food industry in the Czech Republic

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***Keywords*:** automation, food chain, Industry 4.0, logistics, production.
Abstract: The food industry is the most important sector of the national economy of the Czech Republic, which significantly contributes to the fulfillment of fundamental macroeconomic aggregates such as gross domestic product, employment, exports and others. The food industry is currently facing pressure from customers for higher quality and safety while maintaining low prices. At the same time, however, they must ensure high safety and productivity of their production and logistics flows when there is a shortage of manpower. Another aspect is the sustainability of logistics and supply chains, i.e. the requirement for new materials, packaging and technologies enabling maximum processing and use of inputs. From this point of view, the application of Industry 4.0 elements to the food industry appears to be a necessary step for the company's competitiveness. The article summarizes the results of a questionnaire survey that took place in the period April-May 2023 through the Internet tool Survio. A structured questionnaire was sent to 206 food businesses in the Czech Republic. The enterprises were selected according to the database of the Ministry of Agriculture. 69 enterprises returned correctly completed questionnaires, which makes the return rate 33%. Questions were directed to the area of process stability as a result of two crises, the Russian-Ukrainian crisis and the Covid-19 pandemic. Further to the field of automation, digitization and robotization to evaluate the current state of involvement of food production in Industry 4.0.

1 Introduction

The agricultural and food sector is a key branch of the Czech industry.The main pillars of competitive food production are food safety and quality. An integral condition of food safety is the safety of production and logistics processes within the entire food chain. This is guaranteed on the one hand by the fulfillment of legislative measures, on the other hand by voluntary certificates and standards. Food production is influenced by the European and mainly domestic market, where the origin of food is more important to consumers than before. From this point of view, an important aspect is transparency in production and logistics, which needs to be ensured within the entire value chain. That is, from the reception of the raw material and its storage to the delivery of the food to the final consumer. As Lukiewska and Juchniewicz emphasize, the food sector is the basis for the growth of Central European national economies from a long-term and sustainable perspective [1]. In recent years, the world has increasingly faced resource scarcity, population growth and climate change, and thus the role of agri-food chains in sustainability issues is growing [2]. In 2020, the food industry was one of the few sectors that managed to achieve the effects of the COVID-19 pandemic. The industrial production of the food industry increased by 0.7% in 2020, from industrial activity increased by 1.6% and financial results by 3.2%. In 2021, the food industry continued to grow, despite additional energy and raw material costs. In the first eleven months of 2021, the food turnover reached industry CZK 314.6 billion, which was 10.6% more than in the same period of 2020 [3]. The food industry is currently facing pressure from customers for higher quality, safety by managing value streams while maintaining low prices. At the same time, however, they must ensure high safety and productivity of their processes when there is a shortage of manpower. In order to ensure the quality control and safety of food products, and further reduce the need for manpower, many production and logistics flows in the food industry are monitored and implemented using automation [4]. Another aspect is the sustainability of logistics chains, i.e. the requirement for new materials, packaging and technologies enabling maximum processing and use of inputs. Supply chains cross the borders of many countries and are based on the cooperation of international organizations. This fact has an impact on competitiveness, as the wide network and complexity of the links in the chain limit traceability and transparency to the desired level [5]. From this point of view, the application of Industry 4.0 elements to the food industry appears to be a necessary step for the company's competitiveness. Malík points out that the world has already encountered major global problems such as

economic crisis and military conflict. The elements of industrial revolution 4.0 can certainly improve the management of production and logistics processes in times of economic crisis [6]. The Fourth Industrial Revolution (called Industry 4.0) is progressing exponentially, driven by the advent of a range of digital technologies and other innovative technological advances [7]. There are numerous challenges facing the modern food and agriculture industry that urgently need to be addressed, including feeding a growing global population, mitigating and adapting to climate change, decreasing pollution, waste, and biodiversity loss, and ensuring that people remain healthy. At the same time, foods should be safe, affordable, convenient, and delicious [8]. New technologies and elements of Industry 4.0 present new opportunities for food businesses to implement traceability systems for aggregating a wide range of data to material and information flows within the entire chain [9]. These technologies would then have a direct impact on the management of material, financial and information flows. The production and logistics processes of the food industry are subject to a number of legislative measures related to product safety. The various stages comprised can be classified as agricultural production and livestock production, food industry, distribution, and consumption. Each stage, except the consumption, adds a specific value to the final product [10]. The main pillars of Industry 4.0 are automation, robotization and digitization. Based on this, there is also talk of logistics 4.0. Processes performed by robotics and automation also provide greater efficiency and a better work environment [11]. Industry 4.0 is a direction that affects production and logistics processes, but it can also be implemented in the areas of trade, agriculture, healthcare and logistics in general. The elements of Industry 4.0 in logistics processes then represent the concept of Logistic 4.0, which is intended to help increase the performance of individual logistics activities and processes [12]. The introduction of Industry 4.0 has many impacts also on the whole supply chain and requires companies to rethink the way they design and manage their supply chain [13]. In the agri-food sector, demands for SCM are increasing due to the requirement to shorten activities and processes throughout the chain. Another requirement is quality control, monitoring of long-distance flows of agri-food commodities, management of these flows with respect to different expirations of food materials and raw materials [14]. The food supply chain is made up of producers, traders and processors who bring the product from supply to demand through logistical processes [15].

Food Logistics 4.0 is a term derived from Industry 4.0, focusing on all aspects of food logistics management based on cyber-physical systems. This concept aims that the integration of real-time information and new elements and technologies will lead to more efficient flow management and logistics for food commodities [16].

2 Methodology

The goal of the contribution is to point out the degree of use of automation and robotization in the food industry, as pillars of Industry 4.0. A number of scientific methods were used in the creation of the contribution. Analysis and synthesis of foreign professional research and their comparison were key methods for critical literary research. The established hypotheses were verified using a quantitative questionnaire survey. The questionnaire was constructed with closed questions in the Survio software tool. Contacts for food companies were drawn from the database of the Ministry of Agriculture. All results were evaluated according to company size. In total, 69 companies took part in the survey, medium-sized companies were most often represented (33.3%; 23 companies). The questions tested the hypothesis: H0. There is no statistically significant relationship between the answers to the monitored question and the size of the company H1: There is a statistically significant relationship between the answers to the monitored question and the size of the company The evaluation was carried out at a significance level of α = 5%. The basic statistical methods were descriptive statistics, Fisher's exact and modified test and Spearman's correlation coefficient.

3 Result and discussion

The main priority of companies in agri-food chains is product safety and quality. The application of automation technology based on Industry 4.0 contributes to the realization of a sustainable food security regime [17]. The author collective monitored the degree of involvement of the company in the process of automation of operation, where 1 represented complete involvement, up to 4, which represented zero involvement. Table 1 shows that micro-enterprises have zero automated operations, and 53.8% of these enterprises do not plan to implement at all (7 enterprises), on the contrary, large enterprises have automated operations in 31.3% of cases (5 enterprises). On the contrary, there is no large enterprise that does not at least plan for automation. To verify the relationships, it is not possible to use the $\chi 2$ test of independence in the contingency table due to the large number of underrepresented categories, as well as the modified Fisher's exact test due to the size of the table. However, since we can consider both variables as ordinal variables, we can use Spearman's correlation coefficient (R = -0.478; p-value <0.001). Since we know that 1 = full automation and 4 = zero automation, with no implementation plan, it can state that as the size of businesses increases, the level of automation increases statistically significantly. Small and medium-sized food manufacturers are currently facing pressure from customers and stakeholders to shorten delivery times and be environmentally friendly in order to maintain a competitive position in the global market. While the adoption of Industry 4.0 is still at an early stage among SMEs, its potential impact on sustainability is expected.

The implementation of the elements of Industry 4.0 in these types of business is still at an early stage, but its potential impact on sustainability is expected [18].

Table 1 The degree of involvement in automation according to the size of the company

Choose the degree of involvement of your business in the process of automation of operations	Company size by number of employees:				Total
	Micro enterprise 1-9 employees	Small business 10-49 employees	Medium enterprise 50-249 employees	A large company with over 250 employees	
The company already has an automated operation	0 (0%)	5 (29.4%)	7 (30.4%)	5 (31.3%)	17 (24.6%)
The company is in the phase of implementing automation elements	2 (15.4%)	5 (29.4%)	13 (56.5%)	9 (56.3%)	29 (42%)
The company is considering automating in the short term (1-2 years)	4 (30.8%)	4 (23.5%)	2 (8.7%)	2 (12.5%)	12 (17.4%)
Thee company is not considering automation	7 (53.8%)	3 (17.6%)	1 (4.3%)	0 (0%)	11 (15.9%)
Total	13 (100%)	17 (100%)	23 (100%)	16 (100%)	69 (100%)

Table 2 shows at which countries the production automation systems were or will be purchased from. Initially, this question was answered by all monitored companies, i.e. even those that do not plan automation at all (just for interest - these companies chose the answer Asia). We considered it appropriate to evaluate this question only for those businesses that are already automated, or at least plan to do so. In that case, there are 58 enterprises. Overall, the most common answer was "Other EU countries". Interestingly, after filtering out businesses that do not plan to automate at all, no one mentioned Asia. There is a statistically significant relationship between the size of the company and the country of origin of the systems (Fisher's modified test; p-value = 0.044). Smaller companies more often prefer Czech systems, on the contrary, large companies prefer systems from other EU countries. Specific elements of automation depend on the type and size of production. In their study, Bader and Rahimifard [19] present a solution to improve the application of industrial robots in food production through the definition of a methodology to identify a flexible automation solution for a specific production requirement. present a solution to improve the introduction of robots for food production through a methodology for identifying a flexible automated solution to a specific production requirement.

Table 2 Origin of automation or planned automation

Systems for traffic automation were/will be procured from:	Company size by number of employees				Total
	Micro enterprise 1-9 employees	Small business 10-49 employees	Medium enterprise 50-249 employees	A large company with over 250 employees	
Czech Republic	5 (83.3%)	9 (64.3%)	9 (40.9%)	4 (25%)	27 (46.6%)
Other EU countries	1 (16.7%)	5 (35.7%)	13 (59.1%)	12 (75%)	31 (53.4%)
Total	6 (100%)	14 (100%)	22 (100%)	16 (100%)	58 (100%)

Consumers as well as other members of the food chain require accurate information in real time. Especially in cases of threat to the health of consumers, immediate traceability of the origin of food is required. Digitalization allows food supply chains to be highly connected, efficient, and responsive to customer needs and regulation requirements [20]. Table 3 shows the stages of the digitization process. Digitization elements are used by 15.4% of micro enterprises, but even 50 % of large enterprises, another 31.3% are currently implementing these elements. As in the previous case, we will verify the relationship between the variables using the Spearman correlation coefficient. In the case of the degree of digitization, we consider 1 = full digitization, 2 = implementation at present, 3 = planned digitization and 4 = rejection of digitization. Based on the test performed (Spearman's correlation coefficient; r = -0.346; p-value = 0.004), we demonstrated a statistically significant relationship between the degree of digitization and the size of the company. As the size of enterprises increases, the relevance of digitization increases. The results of this investigation are also confirmed by Kosior's study [21], where it states that the use of digitization elements to manage production and logistics flows in EU food industry

enterprises is low compared to other sectors and industries. He further states that, in general, a higher degree of digitization was typical for large and very large enterprises that had the necessary resources and were able to use the potential of digital technologies.

Table 3 The degree of the company's involvement in the digitization process

Indicate the degree of involvement of the enterprise in the digitization process	Company size by number of employees				Total
	Micro enterprise 1-9 employees	Small business 10-49 employees	Medium enterprise 50-249 employees	A large company with over 250 employees	
The company already uses elements of digitization	2 (15.4%)	6 (35.3%)	11 (47.8%)	8 (50%)	27 (39.1%)
The company is in the phase of implementing digitization elements in operation	2 (15.4%)	6 (35.3%)	7 (30.4%)	5 (31.3%)	20 (29%)
The company is considering digitization in the short term (1-2 years)	4 (30.8%)	2 (11.8%)	3 (13%)	3 (18.8%)	12 (17.4%)
The company is not considering digitization	5 (38.5%)	3 (17.6%)	2 (8.7%)	0 (0%)	10 (14.5%)
Total	13 (100%)	17 (100%)	23 (100%)	16 (100%)	69 (100%)

Thanks to digitization, which is still on the rise, production models integrate smart technologies such as robotics, artificial intelligence (AI), the Internet of Things (IoT) and others [22]. Digitization represents process change and restructuring in business and production approaches. The author team was also interested in what steps the company takes when implementing or considering digital transformation. Businesses that said they were not considering digitization at all were excluded from this survey. The results are then presented in table number 4. Overall, companies most often approach "a higher level of use of production data analysis and their integration into the user interface". On the contrary, at least to the creation of new business models. Even if there are some differences in the data and large enterprises have a higher representation of individual steps, even if the enterprise is planning or has implemented digitization of operations, there are no statistically significant differences between the size of the enterprise and the implementation of individual steps. Studies [23,24] that deal with the development of digitization elements in the agri-food sector emphasize that digitization significantly helps to increase traceability in the entire food chain. Zhou [25] then states how food firms can improve their sustainability performance through digital traceability practices.

Table 4 What steps the company has implemented in connection with digitization

Steps the company has implemented in connection with digitization	Company size by number of employees:				
	Micro enterprise 1-9 employees	Small business 10-49 employees	Medium enterprise 50-249 employees	A large company with over 250 employees	Total
Total	8 (100%)	14 (100%)	21 (100%)	16 (100%)	59 (100%)
Changing the information communication strategy at the input and output	4 (50%)	13 (92.9%)	12 (57.1%)	12 (75%)	41 (69.5%)
Creation of new business models	3 (37.5%)	1 (7.1%)	4 (19%)	7 (43.8%)	15 (25.4%)
Use of process management in process restructuring	2 (25%)	8 (57.1%)	10 (47.6%)	9 (56.3%)	29 (49.2%)
Building an integrated software platform connecting all elements and processes in the enterprise	4 (50%)	12 (85.7%)	15 (71.4%)	12 (75%)	43 (72.9%)
A higher degree of use of production data analysis and their integration into the user interface	4 (50%)	11 (78.6%)	16 (76.2%)	14 (87.5%)	45 (76.3%)

Table 5 Fisher´s exact test

Fisher's exact test	**P-value**
Changing the information communication strategy at the input and output	**0.065**
Creation of new business models	**0.086**
Use of process management in process restructuring	**0.492**
Building an integrated software platform connecting all elements and processes in the enterprise	**0.365**
A higher degree of use of production data analysis and their integration into the user interface	**0.285**

Table 6 shows the digitization rates used by businesses. They most often use the production planning system. This is also confirmed by Cho's study [26], which says that production planning is a key part of production management of manufacturing enterprises The use of digitization elements in the case of enterprise size differs in all cases mentioned. The mentioned elements are more often used by large enterprises, small enterprises most often use only the production planning system. However, even 93.8% of large enterprises have these systems.

Table 6 Digitalization rates used by business

Do you use these digitization elements in your operation?	Company size by number of employees:				
	Micro enterprise 1-9 employees	Small business 10-49 employees	Medium enterprise 50-249 employees	A large company with over 250 employees	Total
Total	13 (100%)	17 (100%)	23 (100%)	16 (100%)	69 (100%)
Warehouse Management System	1 (7.7%)	9 (52.9%)	17 (73.9%)	13 (81.3%)	40 (58%)
Production Planning System	5 (38.3%)	11 (64.7%)	15 (65.2%)	15 (93.8%)	46 (66.7%)
MES	0 (0%)	6 (35.3%)	9 (39.1%)	10 (62.5%)	25 (36.2%)
EDI	1 (7.7%)	11 (64.7%)	19 (82.6%)	12 (75%)	43 (62.3%)

The industrial world has been experiencing digital transformation and implementation of Industry 4.0 elements and technologies in recent decades. Nevertheless, some sectors of the manufacturing industry lack automation and digitization, in particular the main problem is the design and successful implementation of warehouse automation [27,28]. This assertion is confirmed by research results, where the use of the Warehouse Management System is still insufficient.

4 Conclusions

The food sector is a strategic sector that plays a primary role in ensuring food security and self-sufficiency. The specifics of this industry are food chains with direct links to the agricultural industry and end customers. Like other companies in the processing industry, the food industry is also under pressure for higher process efficiency, rationalization of resources and reduction of production costs. Most food production takes place through mass or batch production. This provides the basis for the use of Industry 4.0 elements, especially process automation. A key factor in food production is traceability throughout the entire chain. Another Industry 4.0 element of digitization can then be a tool for assurance. The research results confirm that the use of automation elements depends on the size of the company. Likewise, the relationship between the use of digitization elements and the size of the company was statistically proven. Other foreign studies also confirm that the level of use of digitization in the food sector is still low. It is mostly associated with the introduction of production planning systems. The use of the MES system within the investigated food companies is assessed as insufficient. This system can provide up-to-date records of measurements of a wide range of quantities and notifications for continuous production. And it provides a solid basis for traceability throughout the food chain. In further research, the author team would like to focus on a more detailed analysis of the production planning system and material flows in connection with Industry 4.0.

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Managing the modification of digital marketing and logistics under the influence of artificial intelligence

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Abstract: The purpose of the study is to develop a methodology for determining the modification of digital marketing and logistics and the peculiarities of their management under the influence of artificial intelligence. A theoretical and methodological analysis of existing research was carried out, relevance and purposefulness of the study is substantiated on the basis of scientific generalization. It has been proven that the functioning of modern business is inextricably linked with transformations, which characterized by the intense influence of artificial intelligence. Development trends have been identified and a classification of the main artificial intelligence technologies has developed, which necessitate the need for effective management of modifications in digital marketing and logistics of modern companies. Structured indicators of the dynamics of development of digital marketing and logistics pressure the influence of artificial intelligence. It is substantiated that the penetration of artificial intelligence into the management of digital marketing and logistics of modern companies leads to their modification, which is due to the automation and optimization of business processes. An economic and statistical analysis of the interdependence of trends in the development of digital marketing and trends in the contract logistics market for the Gulf Cooperation Council was carried out. The interdependence is determined and the main prospects for the development of digital marketing and logistics are argued in the context of the impact of artificial intelligence. The results have practical value and can be used to formulate a methodology for managing modifications in digital marketing and logistics of modern companies.

1 Introduction

The intensity of the processes of internationalization of the world economy is characterized by the gradual creation of a single ecosystem of interaction and business development, which is inextricably linked with the introduction of artificial intelligence technologies. Active penetration of artificial intelligence technologies into various sectors of the economy determines their transformation and improvement of business processes due to maximum automation. There is an urgent need to justify the modification of marketing and logistics under the influence of artificial intelligence technologies, which is the focus of the study. It is important to note that previously artificial intelligence technologies were available to very large companies and holdings, but thanks to intuitive and accessible tools, every business segment has access to them. The introduction of artificial intelligence directly determines the modification of industries and entire companies, not excluding the marketing and logistics management system, which requires detailed research. The introduction of artificial intelligence technologies into the business processes of modern companies significantly simplifies and optimizes activities, modifying them in accordance with technological characteristics. From streamlining companies' operations and business processes to personalizing experiences, AI technologies are already

impacting businesses around the world, offering new opportunities for growth, efficiency, and innovation.

The fulfilment of artificial intelligence technologies in the management of marketing and logistics significantly modifies, which confirms the relevance and necessity of this research. It is important to note that the intensity of implementation of artificial intelligence technologies in all business segments and directions in the world causes many questions and modifications of these industries, which requires detailed research and determination of key aspects. Given that a modern business cannot be presented without an effective marketing and logistics system, the introduction of these technologies generates many directions and activities that should be controlled to ensure effective management of the company as a whole. The modification of marketing and the appearance of its new forms and tools directly affects the logistics processes by improving them based on the fulfilment of artificial intelligence. Artificial intelligence creates many innovative tools for organizing marketing efficiency from communications to sales; helps improve logistics processes, inventory management, and delivery. All this significantly improves competitive positions in the global market and allows one to surpass the competition in a particular niche, which determines the enormous demand and interest in the introduction of artificial intelligence technologies, which radically modify the activities of companies.

The growth of investments in technologies, their implementation and implementation in the most complex areas of marketing and logistics of modern companies are due to the need to improve management efficiency, optimize costs, minimize operational risks and increase profitability. In this regard, artificial intelligence offers many tools for improving, developing and optimizing routine processes in achieving business tasks and goals, which determines the demand and relevance of these technologies in business segments. Based on the above, there is an urgent need to identify key aspects and changes in marketing and logistics management within the framework of the implementation of artificial intelligence, which determines the conceptual need and relevance of research in this area. The study is aimed at identifying trends in the modification of digital marketing and logistics under the influence of artificial intelligence.

1.1 Theory of development of marketing and logistics as a unified management concept

The functioning of modern business and its effectiveness largely depends on the management strategy, which should be based on marketing and logistics as a single management concept, but this was not always the case. Therefore, long-term development of modern companies directly depends on the marketing and logistics management strategy, which determine the key competitive areas in global markets. Based on this, it is worth paying special attention to the concept of marketing and logistics management of companies as a single concept that ensures the achievement of business goals and strategic objectives. To argue the main aspects of the functioning of marketing and logistics as a unified management concept, the author conducted a critical analysis of the scientific literature in this area and argued the main scientific approaches and their specifics.

The relationship and importance of the marketing logistics strategy and the formalization of basic support methods and its implementation are emphasized in study [1]. This approach justifies the consideration of the company's strategy as a single whole of marketing and logistics with the interaction that achieves the set goals. Basic support methods and steps for implementing this strategy are identified, but aspects of modification of marketing and logistics management under the influence of artificial intelligence are not disclosed, which requires improvement and expansion of the research area. The identification of key directions and prospects in the development of marketing and logistics is considered in scientific research [2]. Marketing and logistics formalize the state, the state and prospects for development are determined. This approach reveals the essence of the concept of a unified approach to marketing and logistics management, reveals its relevance and prospects, but the modification of marketing and logistics management, which is caused by the introduction of artificial intelligence technologies, is not stated, which requires detailed study.

The scientific approach [3] deserves attention, which emphasizes the role of marketing and logistics as a factor in the key strategic development of business structures. This approach determines the need and relevance in modern realities for the formation of a strategic approach to managing marketing and logistics as a single goal, a concept with the help of which competitiveness and efficiency are ensured. Therefore, this approach is classical in the formalization of the marketing and logistics system, but does not reveal the features of its modification under the influence of artificial intelligence, which requires detailed study. The relationship and importance of using marketing and logistics as a single whole concept of management in socio-economic systems is revealed in study [4]. The main aspects of the organization of marketing and logistics are argued to ensure the efficiency and optimality of business processes in socio-economic systems, which is quite relevant and in demand in modern conditions. However, this approach does not consider the specifics and main aspects of modification of marketing and logistics under the influence of various factors, including artificial intelligence, which determines the relevance and need for further research. Attention should be paid to study [5], which argues for the role of marketing and logistics in a modern company strategy. The key aspects of the formation of a marketing and logistics management strategy in the context of digitalization and its penetration into all business areas are argued. This

approach reveals the essence of the influence of digital technologies and tools on the marketing and logistics management system of modern companies, but no attention is paid to the influence of artificial intelligence technologies and the modifications that it generates, which requires improvement and further development of this direction. Having stated what has been presented, it should be noted that there are many scientific approaches and studies that determine and bring to light the need for an integrated approach to managing marketing and logistics as a single system. This confirms the theoretical premises formed by the author and requires a detailed study of the features of modification of marketing and logistics under the influence of the processes of introducing artificial intelligence.

1.2 Theoretical aspects of marketing and logistics management under the influence of artificial intelligence

Optimization and the need to automate existing business processes of companies is due to the growing role and penetration of artificial intelligence technologies into all areas of activity. The efficiency of marketing and logistics ensures competitive positions and business scaling opportunities, which are ensured by the introduction of innovations, technologies and tools that are based on artificial intelligence. Arguing the above, it is necessary to analyse the literature and research in the field of introducing artificial intelligence into the marketing and logistics management system of companies, to highlight the main directions, prospects and issues.

A systematic review of the literature regarding the implementation of artificial intelligence in marketing, stated by a group of scientists [6]. This approach argues for the main directions of scientific approaches and methods in terms of studying the introduction of artificial intelligence in marketing. Attention is focused on the main directions of marketing activities of companies that are subject to transformations under the influence of artificial intelligence. The need for the introduction of artificial intelligence technologies with the argumentation of key tools has been identified, but a comprehensive approach to studying not only the features of implementing these technologies in marketing, but also its modification, which requires management and selection of mechanisms to ensure efficiency, has not been disclosed, which requires improvement and detailed study. The role and influence of information technologies on electronic marketing is argued in study [7]. The importance and necessity of introduction information technologies and their innovative tools in the electronic marketing strategy, as its key component, is determined. This approach argues for the role of innovation and information technology in marketing strategy, which is important in modern conditions, especially when forming a company's development strategy, but does not reveal the features of the influence of artificial intelligence technologies on marketing and its interrelated element of the strategy - logistics, which requires detailed research.

The features of the management of logistics centers and their key business opportunities based on the intercalation of digital technologies are argued in study [8]. The key aspects of an effective supply chain in maritime transport are identified, with an emphasis on the role of technology and the digital component. The role of technology in optimizing logistics business processes and ensuring their efficiency is highlighted, which is relevant and in demand in modern conditions. However, it is important to note that this approach does not consider logistics in connection with marketing based on the introduction of technologies based on artificial intelligence, which requires improvement and improved research. The functioning and main aspects of organizing marketing and logistics under the restrictions caused by pandemics are disclosed in scientific sub-section [9]. The vision of this approach is that it states the facts that, despite the restrictions and many obstacles, such sectors of the global economy as marketing and logistics they did not stop developing, but rather transformed and grew through scaling, which is provided by technologies, including artificial intelligence. It is important to note that the features of these transformations of marketing and logistics under the influence of artificial intelligence in terms of strategic management are not taken into account, which requires further research. Non-standard approach [10,11], which highlights the mode of logistics distribution of e-commerce in the context of big data. The results of this study highlight the role of logistics in e-commerce, which is based on technology and ensures the effectiveness of company marketing. These aspects of the study are aimed at formalizing the process of logistics distribution, but do not reveal the main aspects associated with artificial intelligence technologies, which require detail and development.

Having stated the above, it should be noted that the intensity of technology development and its penetration into all sectors of human life raises the need to revise existing management techniques, which should take into account many factors. The intercalation of artificial intelligence technologies in the process of marketing and logistics requires their modification and requires operational management, taking into account the fulfillment of business goals and the achievement of strategic objectives. Based on the results of a critical analysis of scientific approaches, it should be noted that there is no single view and approach to the study of artificial intelligence and the characteristics of its influence on the management process. In contemporary conditions, there is an urgent need to formalize the main aspects of marketing and logistics management of companies under the influence of artificial intelligence technologies, which determines the relevance and purpose of this research.

2 Methodology

2.1 Peer review process

The intensity of development of innovative technologies, tools and techniques that are based on artificial intelligence have a tremendous inspiration on the business processes of companies and requires detailed research and formalization of management methodologies. Taking into account the presented information, the key goal of the study is to extension a methodology for determining the modification of digital marketing and logistics and the features of their management under the influence of artificial intelligence. To determine existing approaches in the literature, theoretical and methodological analysis was applied, on the basis of which the demand and necessity of this study was determined. A classification of the main technologies of artificial intelligence has been developed in the context of its implementation in the marketing and logistics processes of companies, which helped highlight development trends. In order to fulfill the assigned tasks, the study used a tool for economic and statistical analysis of the interdependence of digital marketing development trends and contract logistics market trends for the Gulf Cooperation Council. It is important to state that the analysis and synthesis of the dynamics of statistical data on the development trends of digital marketing and the contract logistics market of the Gulf Cooperation Council (GCC). Represents the final stage of statistical research, which allows us to determine conceptual conclusions and justification of the put forward theoretical hypotheses and prerequisites for further practical recommendations for patterns of the studied phenomena in marketing and logistics of companies.

The parsing is a method of scientific research into trends in the development of digital marketing and logistics under the influence of artificial intelligence. Economic-statistical analysis and its implementation is characterized by the fact that it ensures the development of a methodology that is based on the widespread use of traditional statistical and mathematical-statistical methods in order to control the adequate reflection of the studied processes of implementation of artificial intelligence in the marketing and logistics of companies.

The objectives of the analysis are to determine and evaluate the specifics of modification and management features of digital marketing and logistics trends under the influence of artificial intelligence, by studying their dynamics, structure and determining relationships and patterns, trends in development. Determining tendency in the evolution of digital marketing and logistics, their modification is inextricably linked with data analysis, qualitative analysis of the essence of trends, structuring the basic directions of development and introduction of artificial intelligence technologies, determining relationships and dynamics.

The key stage of conducting statistical research on the information base on the development of digital architecture and logistics under the influence of artificial intelligence is a critical assessment of the source data in terms of their reliability and scientific validity, which in statistical modeling is implemented by methods of a priori analysis, including: 1) identification economically justified and significant cause-and-effect relationships between the elements under study in this case, marketing and logistics; 2) assessment of the homogeneity of the study population; 3) analysis of the nature of the distribution of the population according to the characteristics being studied. One of the fundamental prerequisites for conducting scientifically based statistical analysis, which adequately reflects cause-and-effect relationships and dependencies, trends in the development of digital marketing and logistics and their modification under the pressure of artificial intelligence in dynamics, is the homogeneity of the statistical population. An important prerequisite for obtaining scientifically based results of statistical analysis and modeling is testing the hypothesis that the distribution of empirical data is close to the normal law (1):

$$\bar{X} \approx M_0 \approx M_e \quad (1)$$

One of the disadvantages of this approach to assessing the nature of the distribution is the presence of subjectivity in the analysis of the sufficiency of the deviation value $\bar{X}$ from M_0 and M_e in this case, modification of the management of digital marketing and logistics under the pressure of artificial intelligence. Any population under study, along with the values of features formed under the pressure of indicators directly characteristic of the object being analyzed, may also contain the values of factors obtained under the influence of other factors not characteristic of the object being studied, the so-called anomalous observations. When analyzing dynamic information (trends in modification of digital marketing and logistics under the pressure of artificial intelligence), the most widely used method for identifying anomalous observations, based on the definition of q - statistics, proposed in the work of Khan G. and Shapiro S. [11,12] (2):

$$g_t = \frac{Y^t - \bar{Y}}{\partial_t} - \quad (2)$$

Where, Y_t – individual levels of the series; $\bar{Y}$ - average level of the row; σ_y is the standard deviation of the empirical values of the series levels from their average level. To analyze the dynamics and trends in the development of digital marketing and logistics under the influence of artificial intelligence, as time series, a method based on the definition of λ statistics was used to identify anomalous observations (3):

$$\lambda_i = \frac{|Y_t - Y_{t-1}|}{\varrho_y} \quad (3)$$

If the calculated value exceeds the critical level (with a given level of accuracy and number of observations), then the calculated value is considered anomalous. The proposed methods and approaches for designation tendency in the introduction of digital marketing and logistics under the pressure of artificial intelligence will allow us to argue for key trends in development and will allow us to determine their modification.

3 Result and discussion

The introduction of artificial intelligence and its key technologies and tools in contemporary conditions significantly facilitates companies in the process of studying their consumers, determining their demand, values and behavior. One way this is particularly useful in digital marketing and logistics is through customer recommendation systems, which can include automated and personalized logistics service options, as well as digital marketing efforts such as targeted newsletters and advertisements. The global rise in the use of digital marketing, coupled with the adoption of machine learning techniques in logistics, is significantly influencing several industries. Advanced technologies using artificial intelligence are part of Industry 4.0 and play an important role in driving this growth. There are many benefits of artificial intelligence in digital marketing and logistics, some of which include: the ability to automate processes, effectively manage customer relationships, and continuously improve operational strategies [12]. Taking into account the above, it should be noted that the strategy of modern companies is complex and multifaceted, as it includes many areas, tools, features and specifics of activity, which should be directed as a single system to achieve business goals and objectives. Based on this, the introduction of artificial intelligence technologies into the strategic management of digital marketing and logistics cannot be ignored, as it ensures promising growth and an increase in the level of competition and business scalability. Taking into account what has been presented, it is necessary to consider in detail the main technological aspects of the introduction of artificial intelligence into digital marketing and logistics of companies and the main modifications that they introduce [13,14]. Artificial intelligence plays an important role in the activities of contemporary companies, regardless of the segment and specifics of the activity. Based on this, the author consolidated information regarding the importance of artificial intelligence in the strategic management of modern companies, which is presented in Figure 1.

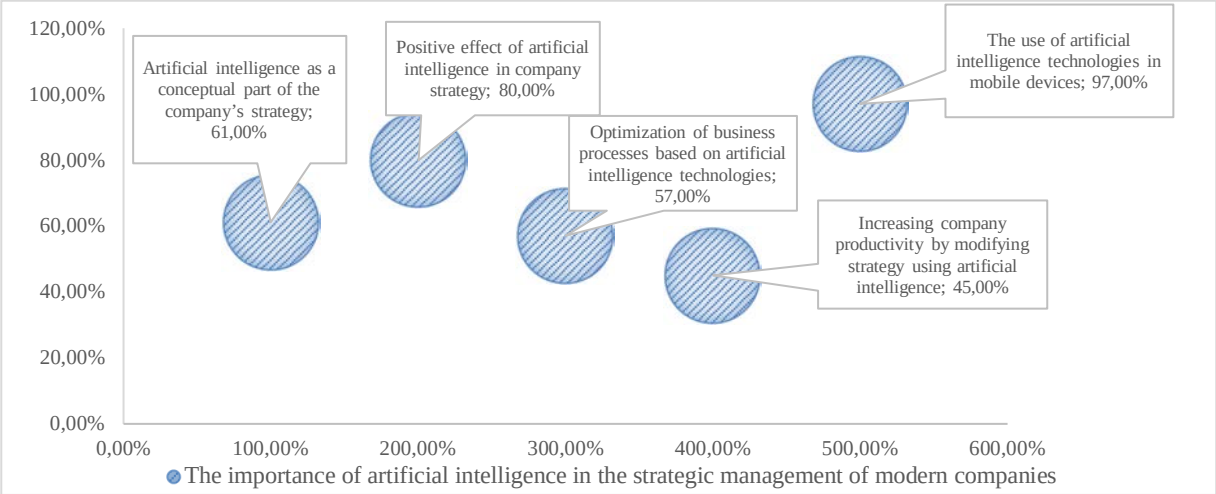

Figure 1 The importance of artificial intelligence in the strategic management of contemporary companies

Based on what has been presented, it is important to state that artificial intelligence technologies are becoming more accessible every day and are being used in every sector of the global economy. The information presented confirms that technologies are reflected in all business processes of companies and lead to their modernization and modification, thereby ensuring economic growth, efficiency and profitability. Based on this, to determine the features of modernizing the management of trends in digital marketing and logistics of companies, it is necessary to consider the classification of the main technologies of artificial intelligence and their introduction in the strategic management of marketing and logistics of contemporary companies. Based on what has been presented, it is important to state that artificial intelligence technologies are becoming more accessible every day and are being used in every sector of the global economy. The information presented confirms that technologies are reflected in all business processes of companies and lead to their modernization and modification, thereby ensuring economic growth, efficiency and profitability. To justify the demand and relevance of the introduction of artificial intelligence technologies, the author has structured the key advantages of these technologies for contemporary business, which are presented in Figure 2.

Managing the modification of digital marketing and logistics under the influence of artificial intelligence

Hassan Ali Al-Ababneh, Firas Jamil Alotoum, Mahmud Agel Abu Dalbouh, Olga Popova, Ganna Myroshnychenko, Mohamed Ibrahim Mugableh

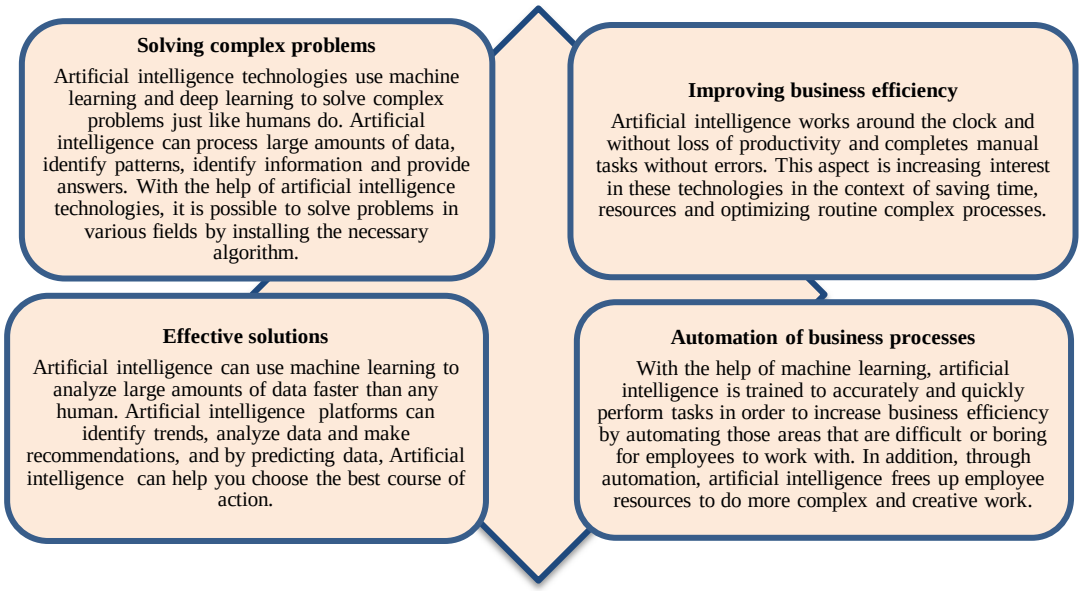

Figure 2 Structuring the key advantages of introducing artificial intelligence technology into digital marketing and logistics of contemporary companies

The introduction of artificial intelligence technologies significantly optimizes the existing business processes of contemporary companies through automation, machine learning and increasing their effectiveness, which is actually the reason for the wide range of their application, which leads to transformation processes and modifications of a particular industry. Based on this, to determine the features of modernizing the management of trends in digital marketing and logistics of companies, it is necessary to consider the classification of the main technologies of artificial intelligence and their implementation in the strategic management of marketing and logistics of modern companies. It is important to note that today digital marketing has long been ahead of classical marketing, and artificial intelligence has transformed and brought the entire industry to a new level based on the introduction of these technologies [15,16]. This modification of digital marketing and the intensity of introduction processes are characterized by the fact that these technologies make it possible to simplify the company's work in the digital sphere, and allow consumers to receive a higher quality and improved customer experience. The ranging of key artificial intelligence technologies that modify the digital marketing of companies is presented in Table 1.

Table 1 Ranging of key artificial intelligence technologies that modify digital marketing of companies

ARTIFICIAL INTELLIGENCE TECHNOLOGIES	THE ESSENCE OF TECHNOLOGY	SPECIFICS OF MODIFICATIONS DIGITAL MARKETING
CONTENT GENERATION	Tools based on artificial intelligence allow you to quickly and easily generate content plans, create posts for social networks, slogans, advertising messages, articles, pictures, audio and video. This greatly optimizes the business process of developing materials, texts and content in general.	Modification of the content preparation process, optimization of the company's human resources and reduction of operating costs.
AUTOMATION OF MAILINGS	Communication with clients through mailing lists and instant messengers no longer requires many physical resources. Using artificial intelligence technologies, a company can interact with clients around the clock: consult, register, nurture leads, and accept orders based on the implementation of artificial intelligence and machine learning.	Optimization of routine business processes, transparency and increased efficiency. Freeing up additional company resources in both human and financial dimensions.
DATA ANALYSIS	Using artificial intelligence, companies analyze the results of marketing campaigns, build predictive models of customer behavior and improve their digital marketing strategy.	Increasing the level of reliability and accuracy of information based on big data analysis and manual labor automation. Saving time and financial costs for paying for analytical studies.

CUSTOMER SEGMENTATION	Artificial intelligence tools study and analyze customer information to determine key criteria for effective segmentation. Rational division of customers into groups and segments helps to personalize offers, optimize marketing costs, and increase company profits.	Freeing up time, human and financial resources due to the automation of routine processes.
PERSONALIZED APPROACH TO THE CLIENT	Without technology, it is difficult to predict the buyer's next move and make an offer that will interest him. Artificial intelligence can analyze behavioral factors such as clicks, purchases, search queries and recommend the most suitable products to the client.	Improving the quality of customer service through a personalized approach, reducing manual labor, optimizing the process of analysis, and marketing research.
INCREASED CUSTOMER SATISFACTION	Automation of the process of communication with clients and personalization of offers improves the quality of service. The level of customer satisfaction and, consequently, their loyalty increases.	Improving the quality of service, simplifying the procedure for establishing communications and studying the client.
SEARCH ENGINE OPTIMIZATION	Artificial intelligence helps analyze data, develop and improve a content strategy, generate content optimized for search engines, think through promotion and thereby increase traffic growth.	Automation of the process of setting up and integrating search algorithms. Economics in monetary and time equivalent to the need to attract hotel companies and specialists.

Conceptualizing, it should be noted that if before the introduction of artificial intelligence technologies in marketing business processes, it took a lot of time to connect the team, determine the main tasks and goals of the marketing strategy. Today this has been modified and in a matter of minutes, with the help of artificial intelligence technologies, it will be possible to complete a number of marketing tasks while increasing efficiency, quality of service, reducing costs and optimizing business processes. Artificial intelligence simplifies and makes intuitive the complex, multifaceted processes that underlie the functioning of any company. Definitely, for the strategy of modern companies to be effective, digital marketing must be inseparable from logistics. Artificial intelligence in logistics is having a similar impact as digital marketing, transforming what was once a linear, predictable process into a dynamic and intelligent business process. Artificial intelligence technologies have found wide application and are redefining the boundaries of what is possible in the logistics industry. Artificial intelligence radically modifies logistics processes, leads to their optimization, job reductions, and focuses on data confidentiality and the ethical use of technology [17,18]. Based on what has been presented, in order to argue for the management methodology and determine the modification of digital marketing and logistics under the influence of artificial intelligence technologies, we should consider the ranging of key artificial intelligence technologies that modify the logistics of modern companies, which is indicated in Table 2.

Table 2 Ranging of key artificial intelligence technologies that modify the logistics of contemporary companies

ARTIFICIAL INTELLIGENCE TECHNOLOGIES	FEATURES OF THE IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES AND MODIFICATION OF LOGISTICS
AUTONOMOUS VEHICLES AND DRONES	The implementation of artificial intelligence technologies in vehicles contributes to the emergence of new vehicles and drones. Drones and autonomous vehicles are the epitome of artificial intelligence in logistics, providing a high level of scalability and efficiency for the business of not only goods, and are driving improvements in the speed, flexibility and agility of the supply chain. The dissemination and implementation of these technologies allows companies to modify management approaches by optimizing logistics routes to increase efficiency.
PREDICTIVE ANALYTICS	The analytical component of artificial intelligence to process huge volumes of historical data to predict future trends, demand patterns and needs for inventory and delivery of goods. This trend forecasting is critical in logistics because it allows data-driven strategic decisions to be made that improve operational efficiency. These artificial intelligence tools allow logistics companies to stay one step ahead of market demands and potential disruptions.
ROBOTICS BASED ON ARTIFICIAL INTELLIGENCE IN WAREHOUSES	The implementation of artificial intelligence technologies in warehouse operations has become a real revolution in the field of logistics of companies. Intelligent robots are now capable of automating complex tasks such as picking, packing, sorting and transporting goods. It is important to note that these are not homogeneous robots that undergo training and improve their knowledge over time thanks to machine learning, thereby constantly increasing their productivity and profitability of the company.
INTELLIGENT FREIGHT COORDINATION	The introduction of artificial intelligence technologies will radically transform the way cargo transportation is coordinated. These technologies implement multifaceted interaction algorithms and companies, when organizing logistics, can select the most suitable transportation from carriers. This not only optimizes logistics efficiency, but also reduces operating costs. The use of artificial

	intelligence simplifies booking procedures, improves cargo tracking and significantly improves overall customer satisfaction.
ONLINE SHIPMENT TRACKING AND MONITORING	The functioning of modern business is based on information, which is of critical importance. Online tracking and monitoring of cargo and goods deliveries using artificial intelligence technologies ensures the transparency of the entire supply chain. These technologies ensure that both companies and their clients can track and monitor the movement of their goods and cargo online at every stage. Technological solutions in the field of online tracking and monitoring of cargo and goods deliveries not only improve the quality of customer service, but also ensure effective supply chain management for modern companies.

Having stated the above, the introduction of artificial intelligence and machine learning is radically modifying the business segments of contemporary companies, including marketing and logistics management systems. From optimization of operations and key business processes to a personalized approach to service, learning needs and preferences to autonomous logistics and service systems. It is important to note that these technologies have already influenced businesses around the world, modernizing and modifying traditional business processes with the help of new artificial intelligence capabilities for future growth, increasing efficiency, profitability and minimizing operating costs [19,20]. Undoubtedly, in modern conditions there are colossal transformations in the strategic management of marketing and logistics of companies, which are caused by the implementation of artificial intelligence technologies. Based on this, in order to substantiate the main aspects of managing the modification of digital marketing and logistics of companies, it is necessary to determine the key tendency in the evolution of digital marketing and logistics of contemporary companies with justification for the statistical observed anomalies.

The intensity of development and introduction of artificial intelligence methods in digital marketing in the world is one of the most rapidly developing industries, which requires detailed study and research. It is important to note that many companies are constantly searching for solutions and new approaches to improve and optimize marketing business processes, increase efficiency and profitability, which are provided by artificial intelligence technologies, which cause its maximum modification. Attention to trends in the development of digital marketing allows companies to significantly accelerate and transform their strategy in accordance with trends and innovations for business scaling, sales growth and the long-term development of the company brand [21]. Using artificial intelligence, companies significantly simplify the process of studying and researching consumer behavior, which affects the company's business indicators of interest, profitability, cost reduction, increased efficiency and market scaling. Trends in the implementation of artificial intelligence technologies in digital marketing of companies and the structure of key tools are presented in Figure 3.

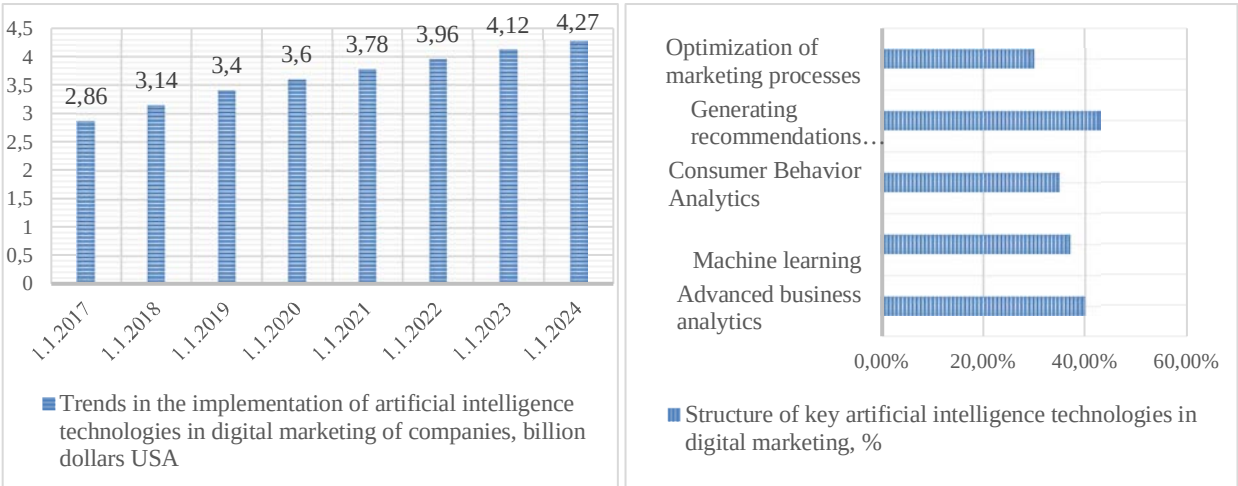

Figure 3 Trends in the implementation of artificial intelligence technologies in digital marketing of companies and the structure of key tools

Summarizing what has been presented, it should be noted that the introduction of artificial intelligence technologies and key tendency indicate that these technologies are radically modifying digital marketing and its management. Artificial intelligence and its key tools stimulate profit growth, new approaches retain customers and allow more accurate targeting of target audience segments and reliably, loyalty and effective communication with clients is built [22,23]. The introduction of artificial intelligence greatly simplifies,

optimizes and improves the management of digital marketing of companies.

Having stated the above, it should be noted that contract logistics of the Gulf Cooperation Council (GCC) demonstrates only positive development trends and an increase in its volumes in key countries. The implementation of artificial intelligence technologies increases the intensity of development, contributes to the transformation of marketing and an increase in sales volumes through e-commerce, which increases the volume of supply chains. The contract logistics market of the Persian Gulf countries is extremely fragmented and gaining popularity every day. Logistics is the best way for local companies to adjust the process with the growing cross-border flow of goods, while simultaneously expanding their logistics processes based on artificial intelligence technologies, reducing costs through centralized suppliers and industrial zones. The largest participants in the logistics market of the Persian Gulf countries are the following: Agility Logistics Pvt. Ltd, Gulf Warehousing Company QPSC (GWC), Al Futtaim Logistics, Almajdouie Logistics Co. LLC and Ceva Logistics. These market players dictate their rules to the rest and integrate technological aspects as much as possible in the development of logistics [24,25]. Based on the presented, for the argumentation of the main aspects of the modification of digital marketing and logistics of companies under the impact of artificial intelligence, it is necessary to consider the trends in the development of contract logistics of the Gulf Cooperation Council (GCC). Growth in E-commerce Driving the Market, and the features of the implementation of artificial intelligence technologies, which are presented in Figure 4.

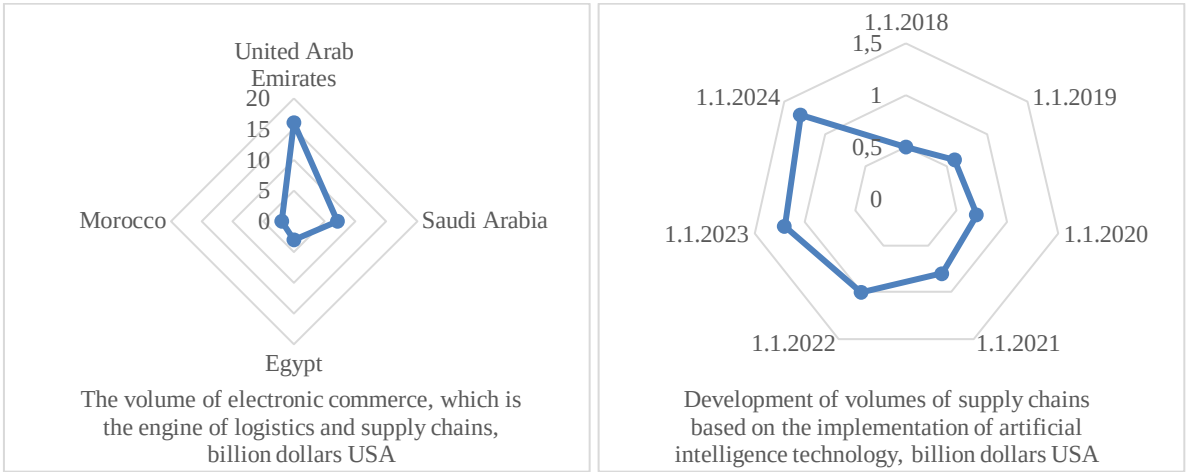

Figure 4 Trends in the implementation of artificial intelligence technologies in contract logistics of the Gulf Cooperation Council (GCC) and Growth in E-commerce Driving the Market the features of the implementation of artificial intelligence technologies

Stating what has been presented, it should be noted that the trends in the development of technologies of the artificial intellect in the world have flooded all branches of the world economy. These technologies are in demand and relevant in the formation of modern companies from the strata of development, so that they ensure the optimization and increase in the level of efficiency of business processes. Consideration of tendencies and trends in the development of artificial intelligence allowed us to substantiate their importance and demand in the field of digital marketing and logistics, which envisage their radical modification and maximum automation of all aspects [26]. In order to interpret the key results of the study on the determination of trends in development and modification of digital marketing and logistics under the influence of artificial intelligence, the main results of the economic and statistical a priori analysis should be cited, which are presented in Table 3.

The interpretation of the main results of the a priori analysis made it possible to reveal the abnormality. interrelationship. and dependence of the processes of modification of the management of digital marketing and logistics under the influence of artificial intelligence [27-29].

Table 3 The main result of the economic and statistical a priori analysis of the management of the modification of digital marketing and logistics under the influence of artificial intelligence

ANALYSIS PERIOD	STATISTICS λ OF MODIFICATIONS OF DIGITAL MARKETING AND LOGISTICS UNDER THE INFLUENCE OF ARTIFICIAL INTELLIGENCE TO DETECT ANOMALOUS OBSERVATIONS		
	Modifications of digital marketing	Modifications of logistics	Interpretation of the level of communication on the modification of the dependence of digital marketing and logistics in the context of the introduction of artificial intelligence technologies

01.01.2018	2.8	3.7	A strong level of communication and interdependence of process modifications
01.01.2019	2.2	2.9	A strong level of communication and interdependence of process modifications
01.01.2020	1.5	2.1	The average level of connection and interdependence of process modifications
01.01.2021	1.7	2.0	A strong level of communication and interdependence of process modifications
01.01.2022	1.8	1.9	The average level of connection and interdependence of process modifications
01.01.2023	2.1	2.4	Low level of communication and interdependence of modification processes
01.01.2024	2.0	2.5	A strong level of communication and interdependence of process modifications

The main task of statistical research at the stage of a priori analysis is the selection of homogeneous groups of indicators that are interdependent and affect the performance indicator. in this case. the profitability of the company. It is important to note that the growing pace of development and implementation of artificial intelligence in marketing leads to the growth of e-commerce. which is directly related to logistics and inventory management. Arguing the above. it should be noted that artificial intelligence technologies not only modify the marketing and logistics of a company. they stimulate the growth of competition. technologies. services and the optimization and improvement of existing business processes of companies. The introduction of artificial intelligence in logistics and automation of supply chains. inventory and warehouse management lead to a significant reduction in costs for business and helps to minimize errors in product delivery. However. due to high initial costs. a long period of achieving return on investment limits the mass implementation of solutions for automation and optimization of logistics processes and requires a search for investors.

A colossal leap in scaling artificial intelligence technologies was caused by a pandemic in which the implementation of artificial intelligence was carried out in a short time with large budgets. From what has been presented. it should be noted that the modification of digital marketing and logistics management under the influence of artificial intelligence technologies has a significant role and influence on the company's strategy. its competitiveness and affordability. The study. research and definition of such modifications. which are called for by the implementation of artificial intelligence technologies. are important and necessary in modern conditions.

4 Conclusions

The conclusion of the study are that the need and relevance of studying the processes of modification of digital marketing and logistics and their management under the influence of artificial intelligence is formalized. The intensity of technology development and its implementation in all areas of the global economy is of great interest in business as part of optimizing existing business processes. reducing costs and increasing efficiency. It is substantiated that the introduction of artificial intelligence technologies is conceptually necessary for modern business of companies. since a high level of competition and the need for scaling are impossible without their use.

To substantiate the main theories of the evolution of artificial intelligence and its introduction in marketing and logistics. a critical analysis of scientific approaches and research was carried out. It has been determined that it is conceptually necessary in contemporary conditions to ensure the efficiency and profitability of a business to formulate a strategy in such a way that marketing and logistics are a single integrated whole. On the basis of scientific generalization. the theory and specifics of the evolution of artificial intelligence in the world. and the features of its application in digital marketing and logistics of companies are determined. It has been proven that the functioning of contemporary business is inextricably linked with transformations characterized by the intense influence of artificial intelligence on all existing business processes of companies. To confirm theoretical hypotheses and premises. a methodology for studying the modification of digital marketing and logistics and management features under the influence of artificial intelligence has been defined.

The trends in the introduction of artificial intelligence in the world are highlighted. on the basis of which a classification of the main technologies and tools that are relevant and in demand in business has been developed.

The role of artificial intelligence in management and its impact on the modification of digital marketing and logistics of modern companies are substantiated. The indicators of the dynamics of digital marketing and logistics development under the influence of artificial intelligence in the world are structured in the context of technologies and areas of their application. It is substantiated that the penetration of artificial intelligence into the management of digital marketing and logistics of modern companies leads to their modification, which is due to the automation and optimization of business processes that stimulate sales growth, business scaling and increasing its profitability. Based on the formulated

theoretical aspects and hypotheses, the need to use economic-statistical and a priori analysis and identify anomalies in the interdependence of digital marketing development trends and contract logistics market trends for the Gulf Cooperation Council is substantiated. Interpretation of the key results of the economic-statistical a priori analysis of digital marketing and logistics modification management under the influence of artificial intelligence confirmed the levels of interdependence and argued the main prospects for the evolution of digital marketing and logistics in the context of the influence of artificial intelligence.

The obtained results can be used as a basis for further research and expansion of the area of defining the processes of modification of the digital marketing and logistics system of companies. The theoretical aspects and methodological approaches to defining modifications of digital marketing and logistics and the features of their management are conceptualized and have independent value and practical significance. The results of the study can be applied in practice when building marketing and logistics strategies as a single management concept in terms of arguing the features of modifications under the influence of artificial intelligence. The developed methodology can be supplemented and expanded depending on the specifics of the companies' activities and the indicators that will serve as the information base for the study.

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Boosting customer loyalty through marketing distribution, customer experience management and customer relationship management
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Boosting customer loyalty through marketing distribution, customer experience management and customer relationship management

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Keywords: marketing distribution, customer experience management, customer relationship management, customer loyalty.
Abstract: This study aims to analyze the effect of marketing distribution on customer experience management (CEM), customer relationship management (CRM), and customer loyalty. This study also analyzes the effect of CEM and CRM on customer loyalty. This study uses quantitative methods with a population of all BPRS (Sharia People's Financing Bank) customers in the Cirebon area, West Java. The sample in this study was taken through the purposive sampling method regarding sampling criteria tailored to the research objectives. From the sampling process, we obtained 185 respondents who met the criteria and became the research sample. Data were collected through the distribution of questionnaires and analyzed using a structural equation model with Smart-PLS 3. The analysis shows that marketing distribution positively affects customer experience management, customer relationship management and customer loyalty. Furthermore, customer experience management and customer relationship management are also proven to positively affect customer loyalty. Conclusion: It is concluded that marketing distribution has an important role in improving CEM, CRM and customer loyalty. This research proves that the implementation of good marketing distribution can encourage consumer interest in the company's products and services and build customer loyalty.

1 Introduction

The world has entered an era where convenience, speed, and simplification are the most preferred aspects by consumers [1,2]. This condition is caused by the rapid advancement of technology, which can facilitate all human affairs [1]. Some literature reveals that technology spoils humans, and humans normalize these conditions so that demands arise for the industry to provide convenience, speed, and simplification of processes for consumers [3]. When in one industry there are new players who offer innovations and breakthroughs that are more attractive to consumers, competitors who are even market rulers must compensate for these new players with the same innovations or substitutes for the innovations offered by competitors [1].

In the context of marketing, one of the aspects that can attract more consumers and build consumer loyalty is marketing distribution [4-7]. Marketing distribution is transferring products, goods and services, from producers to consumers through marketing [4]. Marketing distribution is also a strategy in placing several marketing channels according to consumer interests and needs [7]. So from this definition, marketing distribution is the primary key to attracting consumers to buy a product. With the right marketing distribution, consumers will get convenience, speed and simplification following their expectations.

Analysis of the effect of marketing distribution on consumer loyalty is rarely found in the previous literature. [4] analyzed the effect of marketing distribution on customer satisfaction and purchasing decisions. These two aspects are part of consumer loyalty. Likewise, [6] analyzed the effect of marketing distribution on product quality. On the other hand, marketing distribution analysis is mainly carried out on goods and products, and there is still a lack of literature analyzing service companies. Therefore, analyzing marketing distribution on consumer loyalty in service companies is a novelty this research offers.

Furthermore, the role of marketing distribution is also revealed by some literature to improve customer experience management [4,8,9]. Customer experience management is the management of customers' cognitive, emotional, behavioral, sensory, and social responses to the company. The right marketing distribution will provide a good experience for consumers [10]. When consumers get fast and good service, it will form an experience that can increase consumer loyalty [11]. Likewise, service distribution, supply chain, service completeness, and other marketing distribution aspects can foster positive consumer experiences.

Marketing distribution will create a series of positive influences for consumers [4]. Good distribution will foster a good experience and a good relationship with consumers. Therefore, some literature also reveals the effect of marketing distribution on customer relationship management [12-14]. [12] did not analyze the direct effect of marketing distribution but explained that developing customer relationships requires several aspects of

marketing distribution, namely quality assurance, efficient product distribution, and customer retention. Likewise, [13] found that marketing distribution strategies can improve customer relationships with companies.

This research seeks to fill the gap from previous literature reviews where there is still no analysis conducted on the direct influence of marketing distribution on customer experience management and customer engagement. This research also seeks to analyze the effect of marketing distribution, customer experience management, and customer relationship management on customer loyalty.

2 Literature review

2.1 Customer loyalty

Customer loyalty is the tendency of consumers to buy a product or service from a company with a high level of consistency [15]. Customer loyalty starts with a purchase decision, and then consumers feel an interest in making repeat purchases consistently [16]. Loyalty is related to emotions, so to get consumer loyalty, the company must be able to influence the emotional side of consumers [17]. The emotional side of consumers can be influenced by several things, including marketing distribution [4-6] customer experience management [18-20] and customer relationship management [21-25]. [16,36] explain that the manifestations of consumer loyalty are repeat purchases, recommending others, and giving positive feedback on products or services.

2.2 Marketing distribution

Marketing distribution is the movement of products, goods and services, from producers to consumers through marketing [4]. Marketing distribution is also a strategy for placing several marketing channels according to consumer interests and needs [7]. So from this definition, marketing distribution is the main key to attracting consumers to buy a product, and with the right marketing distribution, consumers will get convenience, speed, and simplification following their expectations. Marketing distribution can be seen and measured from several aspects, namely supply chain time, place of distribution, access to suppliers, access efficiency, and smooth distribution service [4].

2.3 Customer experience management

Customer experience management is the management of the experience of each customer from various points of contact to build a more positive business image [19]. Customer experience management is also the management of the cognitive, emotional, behavioral, sensory, and social responses of customers to the company [20]. On the other hand, customer experience management also functions to track, monitor, and organize every customer interaction [26]. The goal is to ensure customer satisfaction with a pleasant experience. Experience in this context is the customer's perception of a product or service resulting from interactions between consumers and companies [18]. Customer experience management can manifest in several aspects, namely consumer experience in receiving services, consumer experience in using company technology, consumer experience in data security, experience of company care, experience in information availability, experience in handling problems, and experience of company values and culture [26].

2.4 Customer relationship management

Customer relationship management (CRM) manages relationships between companies and consumers [21]. Customer relationship management aims to bring communication between companies and consumers closer [27]. On the other hand, if the company's relationship and communication with consumers are closer, consumers will have more potential to be loyal and not move to competitors [28]. CRM is also a significant factor in fostering company trust; on the other hand, CRM can also be a tool for gathering information from consumers to increase their loyalty and company performance [21,28]. CRM in this era is not only done by direct communication; information technology is one of the most effective media for establishing good relations with consumers [23]. [29] measure customer relationship management in several aspects, namely service delivery, ability to handle consumer problems, speed in responding to consumer needs, and friendliness.

3 Hypothesis development

3.1 Marketing distribution and customer experience management

The right marketing distribution will provide a good experience for consumers [10]. When consumers get fast and good service, it will form an unforgettable experience and benefit the company's image [11]. Likewise, service distribution, supply chain management, service completeness, and other marketing distribution aspects can foster positive consumer experiences. Some literature reveals the role of marketing distribution in improving customer experience management [4,8,9]. Much of the previous literature still focuses on the influence of marketing distribution on the factors of customer experience and has not discussed the direct influence on customer experience. [4] found a relationship between marketing distribution and satisfaction and purchasing decisions as a factor of customer experience [9] related to satisfaction; and [35] related to consumer preferences, which are also part of the customer experience. Therefore, this study seeks to fill the analysis gap by formulating the following hypothesis:

H1: Marketing distribution has a positive effect on customer experience management

3.2 Marketing distribution and customer relationship management

Consumer convenience is offered through marketing distribution, and it is expected that good marketing distribution will increase consumer interest and foster good relationships with consumers [28]. Therefore, some literature reveals the influence of marketing distribution on customer relationship management [12-14]. [12] did not analyze the direct effect of marketing distribution but explained that developing customer relationships requires several aspects of marketing distribution, namely quality assurance, efficient product distribution, and customer retention. Likewise, [13] found that marketing distribution strategies can improve customer relationships with companies. [28] empirically prove that a good relationship with consumers is a competitive advantage not easily imitated by competitors, and good relationships can be optimized with the right marketing distribution [14]. Therefore, this study formulates the following hypothesis:

H2: Marketing distribution has a positive effect on customer relationship management

3.3 Marketing distribution and customer loyalty

Some literature shows indirectly that consumer loyalty can be built through marketing distribution [4-7]. Marketing distribution is transferring products, goods and services, from producers to consumers through marketing [4]. [4] analyzed the effect of marketing distribution on customer satisfaction and purchasing decisions. These two aspects are part of consumer loyalty. Likewise, [6] analyzed the effect of marketing distribution on product quality. On the other hand, marketing distribution analysis is mainly carried out on goods and products, and there is still a lack of literature analyzing service companies. Therefore, analyzing marketing distribution on consumer loyalty in service companies is a novelty this research offers. On the other hand, marketing distribution analysis is mainly carried out on goods and products, and there is still a lack of literature analyzing service companies. Therefore, the analysis of marketing distribution on consumer loyalty in service companies is a novelty offered by this research, so the following hypothesis is formulated:

H3: Marketing distribution has a positive effect on consumer loyalty

3.4 Customer experience management and customer loyalty

Customer experience management was developed to track, monitor, and organize every customer interaction [26]. Several previous studies have found that a good relationship between companies and consumers can foster their loyalty [18-20]. [19] found in their empirical study that customer experience management drives the performance of banking and insurance companies in Jordan. Increased banking performance is a manifestation of customer loyalty. Likewise, [30] found that managing customer experience can encourage customer acceptance of company technology and is an aspect of customer loyalty. The direct effect of customer experience management on customer loyalty was found by 20. [31] also emphasizes that customer experience management is a manifestation of customer loyalty. Therefore, this study formulates the following hypothesis:

H4: Customer experience management has a positive effect on customer loyalty

3.5 Customer relationship management and customer loyalty

The company's relationship and communication with consumers will make consumers potentially loyal and not move to competitors [28]. Some literature also supports the role of CRM in increasing customer loyalty [21-24,15]. Good relationships with consumers are a significant factor so that consumers get to know the company's brand, products, and services better and become loyal [21]. Likewise, [22] proves that the better a company's relationship with its consumers, the more consumer loyalty it will build. However, different findings by [32,33] show no significant effect of CRM on loyalty. The differences in findings in the previous literature indicate an analysis gap, so this study formulates the following hypothesis:

H5: Customer relationship management has a positive effect on customer loyalty

4 Methodology

The analysis in this study used quantitative methods. The population in this study were BPRS (Sharia People's Financing Bank) customers in Cirebon Regency. Samples were taken using the purposive sampling method, which is based on criteria made by researchers referring to research objectives. Criteria in sampling include:

- Respondents are BPRS customers who have been customers for at least 1 year.
- Respondents have savings in BPRS greater than or equal to 5,000,000.
- Respondents routinely make transactions at BPRS at least in 1 month 3 x transactions.

From these criteria, the researcher screened the sample and found that 185 respondents met the criteria and became samples in this study. The data collection technique used a questionnaire with a scale of 1-5, distributed to respondents via a physical questionnaire and Google Form. The data collection results were then analyzed using the structural equation model method with smart-PLS 3 software.

In this study, there are 1 exogenous variable, namely marketing distribution, and 3 endogenous variables, namely CEM, CRM, and customer loyalty. Marketing distribution is measured by four indicators adapted from [4], namely supply chain time, place of distribution, access to suppliers, access efficiency, and smooth distribution service. Then CEM is measured by 7 indicators adopted from [26], namely consumer experience in receiving

services, consumer experience in using company technology, consumer experience in data security, experience of company concern, experience in information availability, experience in handling problems, and experience of company values and culture. Furthermore, CRM is measured by four indicators adopted by [29], including service delivery, the ability to handle consumer problems, speed in responding to consumer needs, and friendliness. Meanwhile, consumer loyalty is measured by four indicators adapted from [16,36], including satisfaction with products and services, repeated purchases, recommendations to others, and positive responses to products or services.

5 Result

The analysis in this study was carried out with a structural equation model using Smart-PLS 3. The analysis is divided into two stages, namely, outer model analysis and inner model analysis. Outer model analysis is a measurement of data validity and reliability, which includes convergent validity, construct validity, and composite reliability. Furthermore, inner model analysis measures the relationship between variables, including the coefficient of determination and path analysis. Outer model analysis is done with the smart-PLS algorithm procedure. Furthemore, the inner model analysis procedure uses the bootstrap method in smart-pls.

5.1 Outer model analysis

Outer model analysis includes convergent validity, construct validity, and composite reliability. In this study, there are 1 exogenous variable, namely marketing distribution, and 3 endogenous variables, namely CEM, CRM, and customer loyalty. Marketing distribution is measured by four indicators adapted from [4], the indicators were adapted and adjusted to the conditions of the respondents in this study and a pilot test was conducted with good results. Then CEM is measured by 7 indicators adopted from [26], and the indicators were adapted and adjusted to the conditions of the respondents in this study and a pilot test was conducted with good results. Furthermore, CRM is measured by four indicators adopted by [29], the indicators were adapted and adjusted to the conditions of the respondents in this study and a pilot test was conducted with good results. Meanwhile, consumer loyalty is measured by four indicators adapted from [16,36], the indicators were adapted and adjusted to the conditions of the respondents in this study and a pilot test was conducted with good results. Convergent validity means testing the validity of each research indicator. The criterion used is the loading factor value > 0.7 [34]. Then construct validity is a test of construct validity with the criteria for an AVE value > 0.5. The composite reliability tests construct reliability with construct reliability criteria > 0.7. The results of the analysis are shown in Table 1.

Table 1 Validity and reliability analysis

Indicators	Loading Factor	Validity	Loading Factor	Validity	AVE	Construct Reliability
CEM1	0.804	Valid	0.804	Valid	0.675	0.936
CEM2	0.874	Valid	0.874	Valid		
CEM3	0.798	Valid	0.798	Valid		
CEM4	0.791	Valid	0.791	Valid		
CEM5	0.830	Valid	0.830	Valid		
CEM6	0.812	Valid	0.812	Valid		
CEM7	0.839	Valid	0.839	Valid		
CRM1	0.880	Valid	0.880	Valid	0.702	0.876
CRM2	-0.002	Invalid	Dropped			
CRM3	0.777	Valid	0.777	Valid		
CRM4	0.853	Valid	0.853	Valid		
LOY1	0.485	Invalid	Dropped		0.587	0.810
LOY2	0.734	Valid	0.758	Valid		
LOY3	0.717	Valid	0.734	Valid		
LOY4	0.793	Valid	0.804	Valid		
MD1	0.804	Valid	0.804	Valid	0.716	0.910
MD2	0.825	Valid	0.824	Valid		
MD3	0.879	Valid	0.880	Valid		
MD4	0.875	Valid	0.875	Valid		

Source: Author's calculation

Table 1 shows that two convergent validity tests were conducted. In the first stage, two invalid indicators were found, namely LOY1 and CRM2, so they were removed from the analysis. Then, in the second analysis stage, it was found that all indicators had met the criteria for a loading factor > 0.7, so all indicators were valid. Furthermore, table 1 also shows that all research variables have an AVE value > 0.5, which indicates that the data has good construct

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validity. Then reliability testing is shown in the construct reliability value, where all variables have a reliability value > 0.7, and it can be concluded that all constructs are reliable.

5.2 Inner model analysis

Inner model analysis is a test of the relationship between variables in the research model. The inner model analysis procedure uses the bootstrap method in smart-pls and the analysis output is shown in Figure 1.

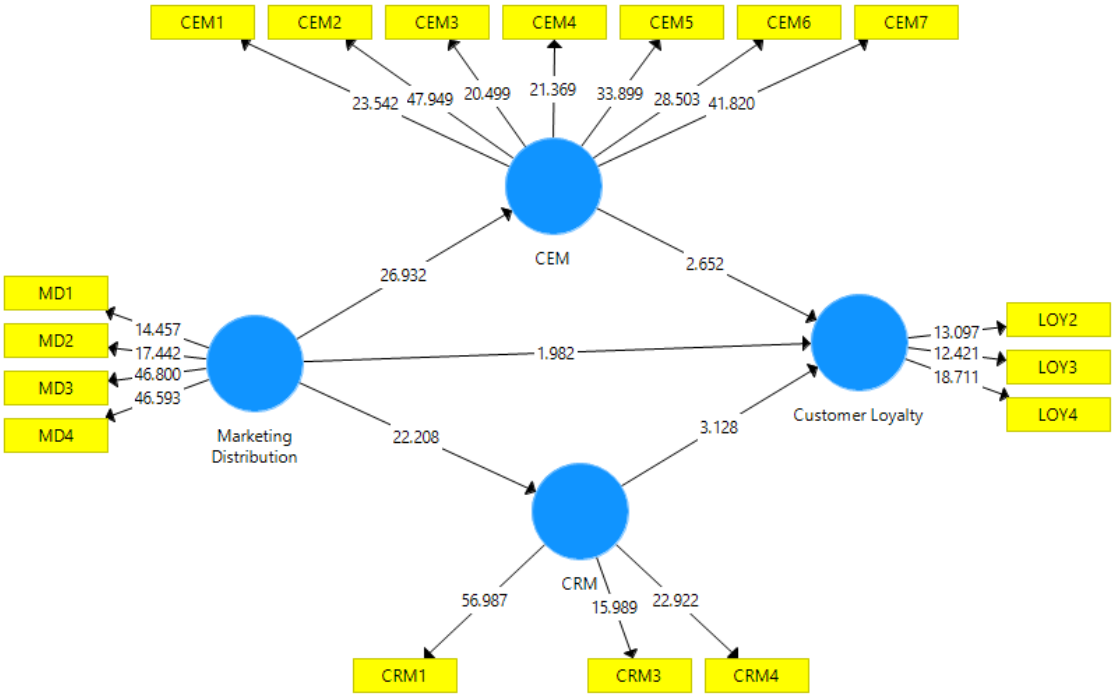

Figure 1 PLS analysis output

The first stage in inner model analysis is the coefficient of determination, which shows how far the model's ability to explain its endogenous variables The coefficient of determination, or R2, is in the range of 0 to 1, where the closer to 1, the greater the influence received by the endogenous variables from the exogenous. There are 3 endogenous variables in this study, namely CEM, CRM, and customer loyalty. The analysis results show that the CEM variable has a coefficient of determination of 61.4%, the CRM variable has a coefficient of determination of 51.3%, and the customer loyalty variable has a coefficient of determination of 50.7%.

The next analysis is testing the research hypothesis based on the results of the path analysis. At this stage, the influence between variables in the study can be seen. The positive effect is shown in the positive original sample value. The significance of the influence is known from the probability value with the criterion p <0.05. The analysis results are shown in Table 2.

Table 2 Path analysis

	Original Sample	T Statistics (|O/STDEV|)	P Values	Hypothesis Result
Marketing Distribution -> CEM	0.784	26.932	0.000	H1 Supported
Marketing Distribution -> CRM	0.716	22.208	0.000	H2 Supported
Marketing Distribution -> Customer Loyalty	0.152	1.982	0.048	H3 Supported
CEM -> Customer Loyalty	0.290	2.652	0.008	H4 Supported
CRM -> Customer Loyalty	0.319	3.128	0.002	H5 Supported

Source: Author's calculation

Table 2 shows that all hypotheses in this study are supported. The effect of marketing distribution on CEM shows a positive and significant value with an original sample value of 0.784 and a p-value of 0.000, so H1 is supported. Furthermore, the effect of marketing distribution on CRM also shows a positive and significant

effect with an original sample value of 0.716 and a p-value of 0.000, so H2 is supported. The findings further prove that marketing distribution has a positive and significant effect on customer loyalty, with an original sample value of 0.152 and a p-value of 0.48, so H3 is supported. CEM is found to have a positive and significant effect on customer loyalty with an original sample value of 0.290 and a p-value of 0.008 so H4 is supported, and CRM also has a positive and significant effect on customer loyalty with an original sample value of 0.319 and a p-value of 0.002 so that H5 is supported.

6 Discussion

This study provides empirical evidence regarding the role of marketing distribution in improving customer experience management, customer relationship management, and customer loyalty. This study found that marketing distribution has a positive effect on customer experience management. So, the better the marketing distribution in the company, the better customer experience management will be. Therefore, companies are expected to be able to optimize marketing distribution as the main key to attracting consumers to buy a product, and with the right marketing distribution, consumers will get the convenience, speed, and simplicity that they expect. To optimize marketing distribution, companies must consider several things, namely supply chain time, place of distribution, access to suppliers, access efficiency, and smooth distribution service [4].

The findings in this study are in line with some previous literature, namely [4,8,9]. [4] found a relationship between marketing distribution and satisfaction and purchasing decisions as a factor of customer experience; [9] related to satisfaction; and [35] related to consumer preferences, which are also part of the customer experience. Much of the previous literature still focuses on the influence of marketing distribution on the factors of customer experience and has not discussed the direct influence on customer experience. Therefore, this research provides novelty by finding a direct effect of marketing distribution on customer experience management.

Furthermore, this study found that marketing distribution has a positive effect on customer relationship management. So if the company can improve the implementation of marketing distribution properly, it can improve customer relationship management. The purpose of customer relationship management is to bring communication between companies and consumers closer [27]. CRM will make consumers more likely to be loyal and not move to competitors [28]. Therefore, this research emphasizes the importance of marketing distribution as an effort to be able to create a good and loyal relationship between companies and consumers.

Some previous literature also supports the findings of this study. [12-14] also prove that marketing distribution can improve customer relationship management. [12] did not analyze the direct effect of marketing distribution but explained that developing customer relationships requires several aspects of marketing distribution, namely quality assurance, efficient product distribution, and customer retention. Likewise, [13] found that marketing distribution strategies can improve customer relationships with companies. [28] prove empirically that a good relationship with consumers is a competitive advantage that is not easily imitated by competitors, and good relationships can be optimized with the right marketing distribution [14].

Further findings in this study again emphasize the importance of marketing distribution. Empirically, marketing distribution has a positive effect on consumer or customer loyalty. Improving marketing distribution performance will increase customer loyalty or increase the number of loyal customers by more than before. Customer loyalty starts with a purchase decision, and then consumers feel an interest in making repeat purchases with high consistency [16]. Loyalty is related to emotions, so to gain consumer loyalty, companies must be able to influence the emotional side of consumers [17]. The emotional side of consumers can be influenced by several things, including marketing distribution.

In line with the findings of this study, some previous literature has also found that consumer loyalty can be built through marketing distribution [4-7]. [4] analyzed the effect of marketing distribution on customer satisfaction and purchasing decisions. These two aspects are part of consumer loyalty. Likewise, [6] analyzed the effect of marketing distribution on product quality as a trigger to foster consumer loyalty. This research provides novelty by finding a direct effect of marketing distribution on consumer loyalty.

Further findings explain that customer experience management positively affects customer loyalty. This finding is supported by several previous studies, namely [18-20]. [19] found in their empirical study that customer experience management drives the performance of banking and insurance companies in Jordan. Increased banking performance is a manifestation of customer loyalty. Likewise, [30] found that managing customer experience can encourage customer acceptance of company technology, and this is an aspect of customer loyalty. The direct effect of customer experience management on customer loyalty was found [20]. This study recommends that companies improve customer experience management through several aspects, namely managing and optimizing consumer experience in receiving services, consumer experience in using company technology, consumer experience in data security, experience of company care, experience in information availability, experience in handling problems, and experience of company values and culture [26].

Furthermore, this study also found that consumer loyalty can also be significantly improved through customer relationship management. This means that the better the company's relationship with consumers, the more customer loyalty will increase. Some literature also

supports the role of CRM in increasing customer loyalty [21-25]. Good relationships with consumers are a major factor so that consumers get to know the company's brand, products, and services better and become loyal [21,37,38]. Likewise, [22] proves that the better the relationship a company has with its consumers, it will build more consumer loyalty. CRM implementation can be done by improving service delivery, the ability to handle consumer problems, speed in responding to consumer needs, and friendliness [29].

7 Conclusion

This study analyzes the effect of marketing distribution on customer experience management, customer relationship management, and customer loyalty. This study formulates five hypotheses, and the analysis results show that all hypotheses are supported. The research findings state that marketing distribution positively affects customer experience management, customer relationship management, and customer loyalty. Furthermore, customer experience management and customer relationship management are also proven to have a positive effect on customer loyalty. This research provides literacy on the direct influence of marketing distribution on customer experience management, customer relationship management, and customer loyalty.

8 Managerial implications

This study recommends that companies, especially BPRS in the Cirebon area of West Java, improve the implementation of marketing distribution, customer experience management, and customer relationship management. To optimize marketing distribution, several things must be considered by the company, namely supply chain time, place of distribution, access to suppliers, access efficiency, and smooth distribution service. This research also recommends that companies improve customer experience management through several aspects, namely managing and optimizing consumer experience in receiving services, consumer experience in using company technology, consumer experience in data security, experience of company concern, experience in information availability, experience in handling problems, and experience of company values and culture. Furthermore, CRM implementation can be done by improving service delivery, the ability to handle consumer problems, speed in responding to consumer needs, and friendliness. These efforts will build customer loyalty and improve company performance. Furthermore, policy makers are expected to be able to encourage the improvement of BPRS Islamic financing literacy, the development of the MSME Community and the development of BPRS common promotion.

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The role of distribution centres in the logistics infrastructure of Kazakhstan
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The role of distribution centres in the logistics infrastructure of Kazakhstan

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Keywords: warehouses, distribution centre, infrastructure, supply chain, logistics.
Abstract: Distribution centres play a key role in the supply chain and their insufficient number will entail supply chain disruptions —supply delays and problems, as well as lost profits. Currently, distribution centres in Kazakhstan are located only in large cities. However, the growth of e-commerce (from 11729.9 billion tenge to 15763.7 billion tenge in 2022 compared to 2020) determines the need to solve this problem. Our study establishes the dependence between the areas of distribution centres and the e-commerce volume. This analysis, unlike the existing ones, examines the effect of the growth of e-commerce volumes on the increasing number of distribution centres as a prerequisite for the development of the logistics infrastructure of Kazakhstan against the background of the increase in the volume of goods supplied from China in transit to Europe. The aim of the study was to analyse the role of distribution centres in the logistics infrastructure of Kazakhstan. We justify the need to increase the number of distribution centres due to the increase in both turnover in goods transit, wholesale, and retail trade. The introduction of distribution centres ensures the continuous movement of goods and strengthens the connection between suppliers and consumers. The emergence of new technologies and innovations, combined with favourable market conditions and political support, creates favourable conditions for the development of reliable distribution centres that can improve logistics efficiency and contribute to the overall economic development of Kazakhstan.

1 Introduction

Most countries pay attention to logistics issues, including joint inventory management, procurement coordination, marketing, and delivery of goods. These key tasks can be fulfilled with the help of distribution centres, which are warehouses for storing goods and products in both small and large centres. Distribution centres play the role of hubs that solve logistical tasks of storing goods in their warehouses on the way to retail networks.

The distribution centre is, first of all, a part of the logistics processes of the movement of goods. The distribution centre will allow the company to improve its work, striving to comply with the logistics rule 7R (right product, right quality, right quantity, right time, right place, right customer, right cost). It provides that the necessary goods of the required quality and in the required quantity will be delivered at the right time without delays, because the goods will be located in the consumer's region, in the right place, to the right consumer with the necessary cost level, as well as with the possibility of reducing delivery costs [1].

The COVID-19 pandemic has once again emphasized the importance of distribution centres in our daily lives. People are increasingly turning to online shopping in order to avoid crowded malls, which has become the new norm. This change in consumer behaviour has had a significant impact on distribution centres, as order volumes increase and customers expect fast delivery. Distribution centres have intensified their efforts to address this challenge. They have managed to cope with the increasing workload on staff and adhere to social distancing measures through the use of new technologies such as automation and robotics. They optimized their processes, ensuring fast delivery of goods and compliance with customer expectations.

Currently, distribution centres in Kazakhstan play a key role in supplying retailers and manufacturers not only throughout the country, but also in the neighbouring countries of Central Asia. This is determined by the fact that Kazakhstan is a transport and transit hub for cargo flows between Asia and Europe [2].

However, in general, the distribution centre sector of Kazakhstan does not fully meet the market needs. One

problem is that many distribution centres in Kazakhstan are located right next to major cities, which makes it difficult to serve regional markets and incurs additional transportation costs. The situation with distribution centres in Kazakhstan is diverse and changing. Some of them operate at a high level, have modern equipment and highly qualified personnel, which enable them to effectively perform their functions and satisfy the customers' needs. But there are distribution centres that require additional investment and modernization of equipment, as well as personnel development. This can lead to poor performance and poor quality of service.

The local market also has prospects for the development of this sector. First of all, the government of Kazakhstan introduced changes to national legislation aimed at stimulating investment in the distribution centre sector. Steps are being taken in this direction to create new distribution centres in remote regions of Kazakhstan, which increases competition in the market and helps to reduce prices for services. The new distribution centres will be able to provide services to retailers in regions where this was previously impossible. In addition, the development of transport infrastructure, including the ports of Aktau and Kuryk, as well as the extensive railway network of Kazakhstan will make transit through Kazakhstan even more attractive for various companies.

Distribution centres not only provide storage of goods, but also assemble batches of goods as quickly as possible for their delivery to the recipient, and also monitor the supply of quality goods. The function of distribution centres to track the supply of high-quality goods for the end consumer, especially in the context of e-commerce, when the consumer cannot physically check the quality of the goods before purchase, determines the relevance and importance of our research not only for Kazakhstan, but also for other countries. Especially for countries where e-commerce is growing rapidly.

The aim of the study is to analyse the role of distribution centres in the logistics infrastructure of Kazakhstan. The aim involved the fulfilment of the following research objective:

- Assess the impact of the development of e-commerce on the growth of the number of distribution centres.

2 Literature review

Much of the efficiency of logistics activities depends on how logistics distribution centres work in supply chains [3]. The term "distribution centre" has various definitions that reveal its essence. On the one hand, a distribution centre is a place created to distribute goods to different users in order to reduce production, inventory management, and transportation costs [4]. On the other hand, a distribution centre, also known as a fulfilment centre or warehouse, is a facility designed to efficiently store, sort, and distribute products [5]. A distribution centre is also defined as a specialized warehouse that acts as a central node in the supply chain, responsible for receiving, storing, and distributing products. It uses technology and automation to optimize inventory management, order processing, and logistics, enabling companies to efficiently meet customer demands [6].

Urban distribution activities account for a significant portion of total transportation spending and are expected to grow due to increased pickup and delivery requests [7]. For these reasons, companies must find logistics solutions in such a way as to reduce costs caused by inefficiency and irrationality [8].

Authors [9] studied the establishment of a logistics centre in the Turkish province of Sivas. The application of a multi-criteria decision-making method was proven to be necessary, as various qualitative and quantitative criteria must be taken into account when creating a logistics centre.

Edgar Hoover proposed three strategies for placing distribution warehouses: near the point of sale of goods, near production, at intermediate points. This has become a commonly accepted classifier. According to the researches of Atameken NEC Centre, trade and distribution centres make it possible to achieve efficiency in the following areas:

- prices for consumer goods will decrease by about 13% on average;
- product losses will decrease by 20%;
- the revenue of agricultural producers will increase by 10% [10].

The above definitions focus on the critical functions of the distribution centre, such as storage, processing, order fulfilment, and transportation management. This strategic component of the supply chain enables companies to effectively manage inventory, reduce costs and improve customer satisfaction.

Authors [11] note that the problem of logistics centres consists, first of all, in optimizing the location of the logistics distribution centre, and it is necessary to apply a special mathematical model to solve this problem. And the type of variables in the model must be taken into account when building a mathematical model. Some of these variables are defined and some are undefined. This model is also reflected in the work [12] in the form of introducing an additional time factor as an undefined variable. Authors [13] proposed that in addition to the uncertain variable of time, uncertainty should also be used in making a decision on the location of a logistics centre. This model is two-stage. Authors [14] studied the three-level optimal location problem in supply chain networks with uncertain transportation costs and uncertain customer demand.

The given analysis shows the influence of factors of time, location, as well as the analysis of variables in the proposed models. However, taking into account the peculiarities of the development of logistics centres in the period of the COVID-19 pandemic, the development of e-commerce is of particular importance. The main condition for the expansion of e-commerce is the use of the capacities

of logistics centres. This is the basis for the importance of our research.

According to studies by domestic authors, the increase in the volume of traffic contributes to the development of distribution centres in Kazakhstan [15]. The development of distribution centres in Kazakhstan was driven by several factors, including the country's strategic geographical location, infrastructure investment, and a favourable business environment. The growth of the e-commerce and retail sectors has also stimulated demand for efficient distribution networks. Moreover, the emergence of new trade routes, such as the China-Kazakhstan-Europe railway connection, further increased the importance of Kazakhstan as a logistics hub. The development of distribution centres in Kazakhstan is mainly concentrated around Astana, Almaty and Atyrau region due to their strategically important location [16].

Based on the proposed methods presented by the above authors, our study proposes to build a regression model (applied by MEDRANO-GÓMEZ, X. D., and FERREIRA, D.) that analyses the relationship between the areas of distribution centres and the e-commerce volume.

In recent years, Kazakhstan has made significant progress in improving its logistics infrastructure. The country ranks 71 in the World Bank's Logistics Performance Index for 2018, which shows a positive trend compared to the previous ranking [17]. There is also an increase in the volume of transportation, the development of digitalization and logistics services in general. Competition in this area has led to the formation of strictly oriented logistics to meet the market needs. As logistics operators need to deliver a large number of individual orders on time, distribution centres are an effective solution to this problem [18]. These researchers themselves propose to consider the relationship between the area of the distribution centres and the e-commerce volume, as such a relationship, in their opinion, is the most relevant for the logistics system of Kazakhstan.

Therefore, the analysis of literature proves that there is currently a gap in the study of the relationship between the dynamics of the expansion of logistics centres and the dynamics of the increase in the e-commerce volume. This issue is especially important for the logistics system of Kazakhstan, in particular because of the significant sanctions for the Russian Federation. Due to the introduction of sanctions against the aggressor country, Kazakhstan became a transit point between the supply of goods from China to Europe, on the one hand, and the supply of sanctioned goods from Kazakhstan to the Russian Federation, on the other hand, which is carried out using electronic systems. All this indicates that Kazakhstan has become a powerful logistics hub and needs additional research into the role of distribution centres in the logistics infrastructure.

3 Methodology

3.1 Research design

The study includes an analysis of the dynamics of transportation volumes and retail sales, an analysis of the possibility of applying the concept of wholesale distribution centres in large cities, an assessment of the impact of the growth of e-commerce on the growth of the number of distribution centres. Figure 1 illustrates the research procedure.

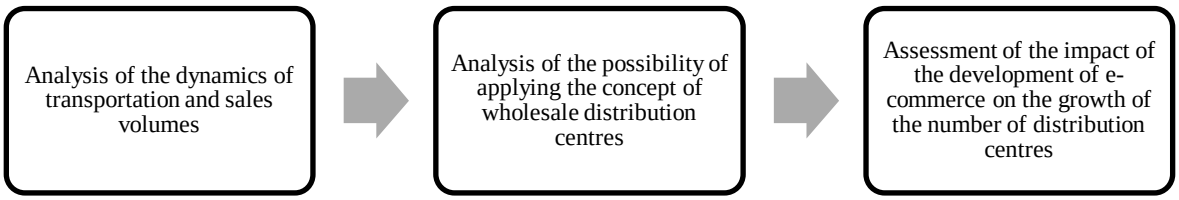

Figure 1 Research design

3.2 Information base

The basis consists of analytical analysis, state programs, statistical data, official information, periodic scientific publications. In addition, in order to study the level of logistics activities, the international LPI (Logistic Performance Index) rating was considered.

The evaluation period is 2020-2022, because it the rapid growth in retail trade is observed during this period, as well as an increase in the volume of retail trade (from 11,729.9 billion tenge to 15,763.7 billion tenge), and an increase in warehouse space by 20% in 2022 compared to in 2020 across the country.

3.3 Methods

The assessment of the impact of the increase in the volume of e-commerce on the increase in the number of distribution centres was carried out using correlation and regression analysis. The choice of such a method is determined by the rapid growth of the volume of e-commerce, which determines the extension of the available distribution centres. The method of paired regression was chosen for the study, where the resulting factor Y is the distribution centre areas, and the independent variable X is the volume of retail e-commerce.

The two-way regression method is used to visualize the relationship between the studied economic indicators. A graph is built for this purpose in a rectangular coordinate system. The values of the resulting characteristic Y are

plotted on the vertical axis, the values of the factor characteristic X — on the horizontal axis.

The set of points of the resulting and factor features is called the correlation area.

The correlation space gives grounds to assume that the relationship between all possible values of X and Y is linear (for the general population).

Linear regression equation y = bx + a

The estimated regression equation (based on sample data) has the form y = bx + a + ε, where ei is the observed (estimated) value of the error εi, a and b are the estimated values of the regression model parameters α and β, respectively.

Here, ε is a random error (deviation, disturbance).

The reasons for the existence of random errors:

1. The regression model does not include important explanatory variables.

2. Aggregation of variables. For example, the aggregate consumption function attempts to represent the sum of individual consumption decisions. This is only an approximation of individual relationships with various parameters.

3. Incorrect specification of the model structure, for example, the model structure is not a model of individual consumer decisions;

4. Incorrect function specification;

5. Measurement error.

For each observation i, the deviation εi is random and its value in the sample is unknown.

1) Only estimates of parameters α and β were obtained from observations xi and yi.

2) Estimates of parameters α and β in the regression model are the values of α and b, respectively, and are random because they correspond to a random sample.

The least squares method (LSM) is used to estimate parameters α and β.

The least squares method provides the best (reliable, efficient, and unbiased) estimates of the parameters of the regression equation only if certain assumptions about the probability term (ε) and the independent variable (x) are met.

Formally, the LSM criterion can be written as follows

$S = \sum(yi - y*i)2 \rightarrow min$

Normal system of equations

$a\text{-}n + b\text{-}\sum x = \sum y$

$a\text{-}\sum x + b\text{-}\sum x2 = \sum y\text{-}x$

The closeness of the relationship is estimated based on correlation and covariance coefficients [19]. The linear correlation coefficient takes on values from -1 to +1. Relationships between signs can be weak and strong (close). Their criteria are evaluated according to the Chaddock scale:

0.1 < rxy < 0.3: weak;
0.3 < rxy < 0.5: moderate;
0.5 < rxy < 0.7: noticeable;
0.7 < rxy < 0.9: high;
0.9 < rxy < 1: very high.

4 Results

The increase in sales, transportation, infrastructure development and e-commerce are the basis for the formation of distribution centers. After all, these factors require a more optimized distribution network for economic growth.

Gross output in the category "Transport and warehousing" for January-February 2023 exceeded 2 483 206.7 million tenge (Ifo 106.7%). This is 57% more than in this period of 2022 (1076470.8 million tenge).

Let us consider the dynamics of the volume of cargo transportation by all modes of transport (Figure 2):

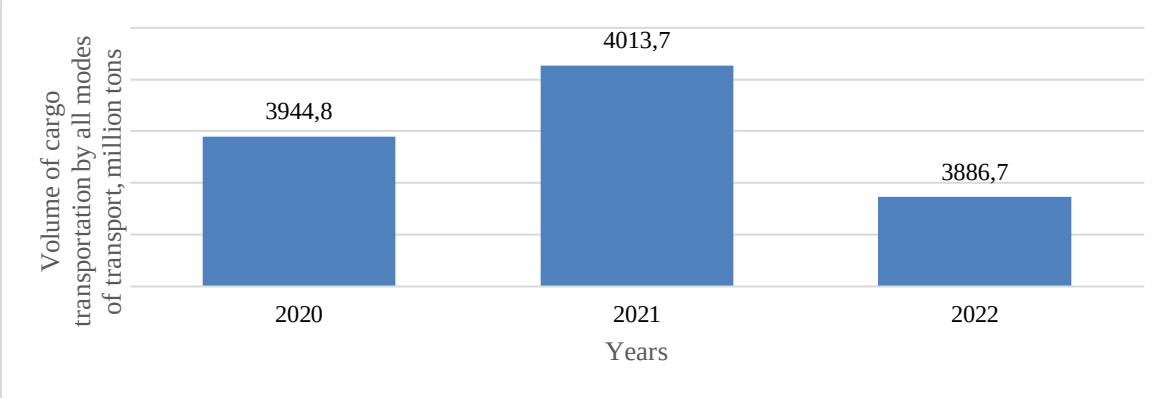

Figure 2 The volume of cargo transportation by all modes of transport, million tons
Note – according to [20]

January-April 2023. transport of the republic transported 307.8 million tons of cargo. Cargo turnover for January-April of this year increased by 1.6% from the level of the corresponding period of the previous year.

In addition, there is a dynamic of increasing the volume of retail trade in the Republic of Kazakhstan (Figure 3).

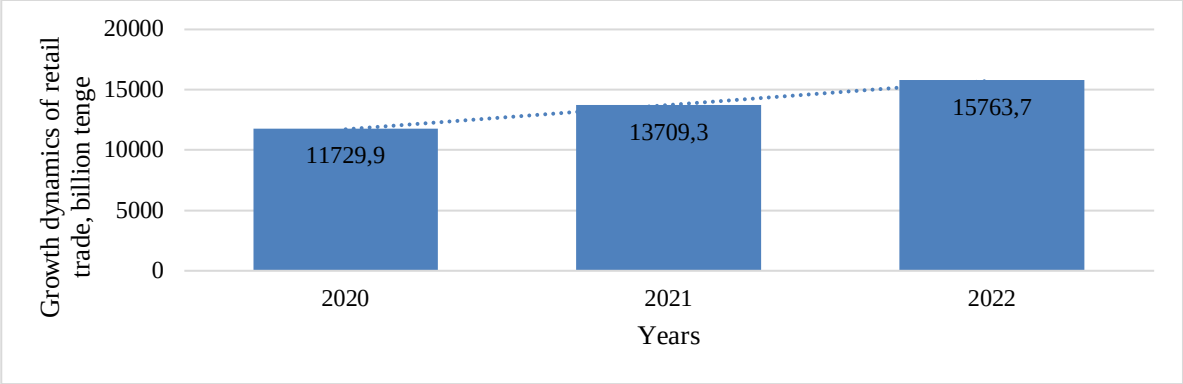

Figure 3 Dynamics of retail trade growth, billion tenge
Note – according to [21]

The volume of retail trade in January-April 2023 amounted to 4825.9 billion tenge, this is 10.5% more than the level of the corresponding period of 2022. Retail sales of goods by trading enterprises increased by 14% compared to January-April 2022.

In the conditions of the developing economy, it is important to pay attention to the creation of effective distribution centres [22]. As companies expand their operations to go global markets, the importance of having a well-planned distribution centre cannot be overemphasized.

According to the National Statistical Service of Kazakhstan, at the end of 2019, the number of distribution centres in Kazakhstan was 27 units, which is 9.1% more than in the previous year. Most of the storage facilities (approximately 60%) are located in the three main cities of the country - Astana, Almaty and Shymkent.

Currently, Kazakhstan has modern distribution centres serving various industries, including retail, manufacturing, pharmaceuticals and consumer goods. These hubs are strategically located near major transportation hubs such as highways, railways and airports, making it easier to deliver goods to various destinations.

The concept of distribution centres in large cities involves the creation of a new system (Figure 4).

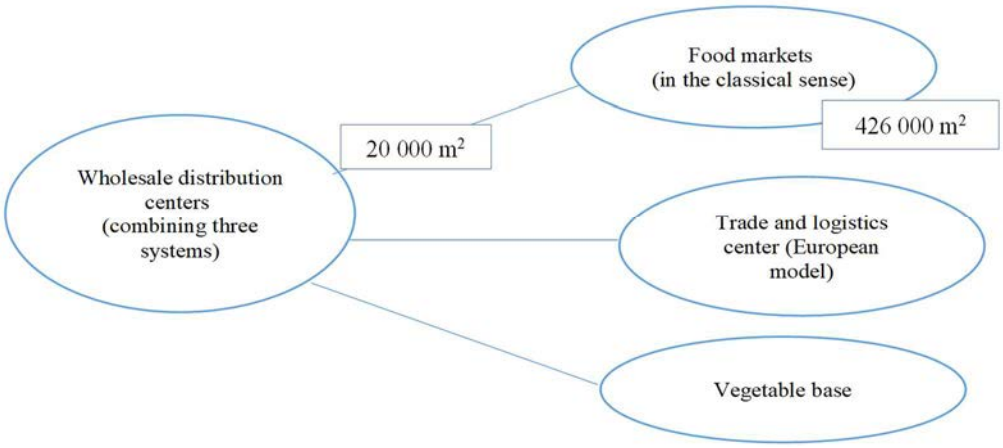

Figure 4 Formation of wholesale distribution centres in large cities
Note – compiled by the authors on the basis of [23]

The presence of a distribution centre allows to reduce the storage area in retail outlets to 30% of the total area of retail premises and exclude intermediaries that can lead to higher prices for goods. In addition, it solves the problem of limited storage space for various types of goods.

Figure 3 gives grounds to note that such wholesale distribution centres focus their activities on three main groups — giant enterprises (a turnover of 100-1000 tons per month), wholesale companies, and retail companies with an average turnover of 10-1000 tons per month. Each of these target groups determines special conditions of cooperation based on the logistics rule 7R (right product, right quality, right quantity, right time, right place, right customer, right cost). One of the examples of the practical implementation of the strategy is the Wildberries marketplace. Wildberries is a leading operator in the field of import, logistics, distribution and promotion of everyday goods from the largest global and Russian manufacturers. The strategic advantage that distinguishes the company from its competitors is that it is able to offer its partner the

entire range of services for the delivery of goods from the manufacturer's warehouse to the final point of sale. Wildberries has opened a new distribution centre in Almaty, thanks to which the Kazakh businesses will be able to increase its presence on the largest Russian marketplace, increase sales, and create new jobs. The distribution centre is managed using the WBPoint mobile application, where entrepreneurs have all the necessary functions for working with orders and customers.

In the first half of 2022, Wildberries increased turnover by 94% compared to the same period last year, reaching 628.7 billion tenge (net turnover from the sale of goods and services to buyers and sellers, including returns). In terms of units, the growth in sales of goods amounted to 77%. In the second quarter, the company's turnover reached 340.1 billion tenge (+92%), which became a new historical maximum. The marketplace has distribution centres in Astana and Almaty. It is planned to open new sorting centres in the cities of Aktobe and Semey. An example of a modern distribution centre is Khorgos located on the border of China and Kazakhstan, which is considered one of the largest dry ports. This terminal provides a full range of cargo handling, storage, and transhipment services. In 2020, traffic volume reached 200,000 twenty-foot equivalent units (DFEs). The main goods transported between the two countries are consumer goods, metals, chemicals, oversized goods, subway cars, and electric vehicles.

Statistics show that the distribution centre sector in Kazakhstan has great economic potential. According to the National Bank of Kazakhstan, the volume of services related to logistics and storage is about $900 million per year. Moreover, the value of trade handled in distribution centres is about $6 billion per year.

Productivity in this field is also high. About 60,000 people work in the distribution centres of Kazakhstan, which is about 2% of the total number of people employed in the economy. In 2019, labour costs in this industry increased by 12.9%.

It is worth noting that Kazakhstan has been actively developing the digital economy in recent years, including in the field of distribution centres. This encourages the adoption of new technologies such as warehouse management systems, e-commerce, etc., which increases production efficiency, shortens delivery time, and facilitates better customer service. The impact of digitalization in distribution centres includes the introduction of automated warehouse management systems, space optimization, real-time inventory tracking and monitoring, greater use of robotics and automation, integration of Internet of Things (IoT) devices, and improved data analytics capabilities.

The volume of storage of goods in distribution centres at the end of 2019 amounted to 14.5 million tons, which is 9.6% higher than the previous year. The main types of storage used in distribution centres include indoor storage warehouses, refrigerated warehouses and warehouses for dangerous and technically complex goods. Distribution centres provide a wide range of services, including storage, shipment, sorting and transportation of various goods, such as food, beverages, body care, household goods, medicines and machinery.

In 2021, the volume of online retail trade amounted to 482 billion tenge. The majority are cell phones or other wireless devices (19%), electrical household appliances (12.6%) and cosmetics and toiletries (11.3%). The volume of wholesale trade through the Internet amounted to 209.8 billion tenge. The share of e-commerce in the total retail trade is 3.6%, and in the volume of wholesale trade this figure is 0.7%. For the period 2016-2021 the volume of e-commerce showed an increase of 84% (Figure 5).

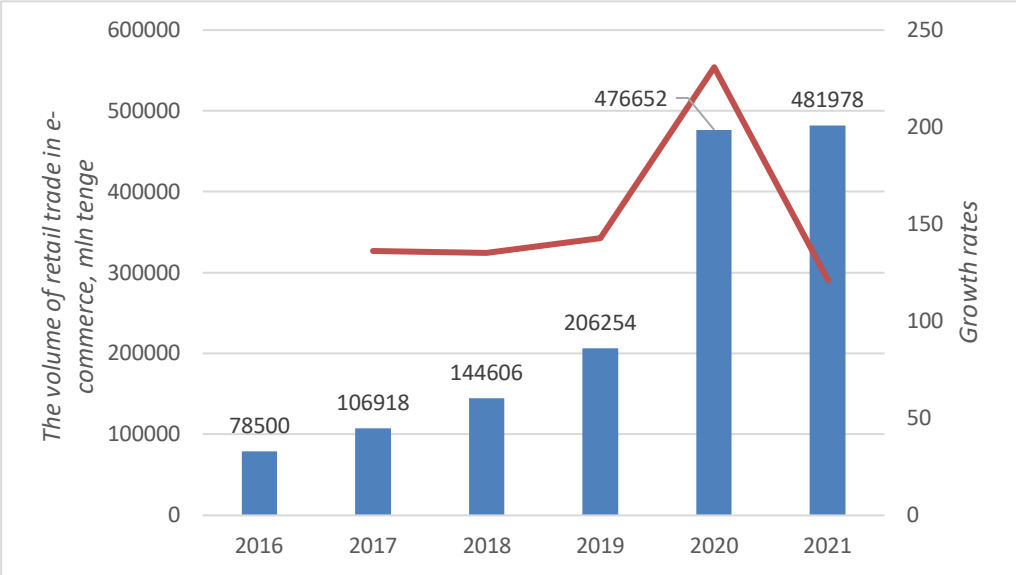

Figure 5 Volume of retail sales in e-commerce for 2016-2021, million tenge
Note – according to [24]

The role of distribution centres in the logistics infrastructure of Kazakhstan

Zhanna Arynova, Gulmira Nakipova, Aigul Nurmaganbetova, Gulzhan Alina, Aigul Orazbayeva, Dinara Kemirkulova

The distribution centre sector in Kazakhstan is also actively developing in the field of e-commerce, where it provides services for the delivery and storage of goods ordered in online stores. The final stage of the research design is a correlation and regression analysis conducted in order to determine the relationship between the need to increase the area of distribution centres, as an indicator of the presence of a distribution centre, and the volume of e-commerce.

The study is based on pairwise regression, where:

Y - the area of distribution centres, million square meters;

X - volume of retail sales in e-commerce, million tenge.

The initial data for the correlation and regression analysis are given in Table 1.

Table 1 Output data for a correlation and regression analysis

X	Y	X^2	Y^2	X x Y
471324.3	3.7	222146595770.49	13.69	1743899.91
476651.5	4.2	227196652452.25	17.64	2001936.3
481978.7	4.5	232303467253.69	20.25	2168904.15
487305.9	5	237467040174.81	25	2436529.5
1917260.4	17.4	919113755651.24	76.58	8351269.86

Based on the data in Table 1, a system of equations is obtained:

4a + 1917260.4·b = 17.4

1917260.4·a + 919113755651.24·b = 8351269.86

The solution of the system is the following steps:

1)-1917260.4a -918971860352.04 b = -8340082.74

1917260.4*a + 919113755651.24*b = 8351269.86

2) 141895299.2*b = 11187.12

3) b = 7.8840666766742E-5

4) 4a + 1917260.4*b = 17.4

4a + 1917260.4*7.8840666766742E-5 = 17.4

4a = -133.758

a = -33.4395

We get the empirical regression coefficients after the presented calculation: b = 7.8840666766742E-5, a = -33.4395 and the regression equation: y = 7.8840666766742E-5 x -33.4395. Table 2 shows regression statistics based on the given calculation.

Table 2 Regression statistics

Regression statistics					
Multiple R	0.998417408				
R-squared	0.99683732				
Normalized R-squared	0.993674639				
Standard error	0.032659863				
Analysis of variance					
	df	*SS*	*MS*	*F*	*Significance of F*
Regression	1	0.3362	0.3362	315.1875	0.035820939
Remainder	1	0.001066667	0.001067		
Total	2	0.337266667			

The calculation of the covariance coefficient indicates the closeness of the relationship: cov(x,y) = x·y - x·y = 2087817.465 - 479315.1·4.35 = 2796.78, and the correlation coefficient:

$$r_{x,y} = b \cdot \frac{S(x)}{S(y)} = 7.8840666766742E-5 \cdot \frac{5955.991}{0.472} = 0.995$$

Such indicators demonstrate a close linear relationship between dependent Y and independent X, according to the Chaddock scale, which is illustrated in Figure 6.

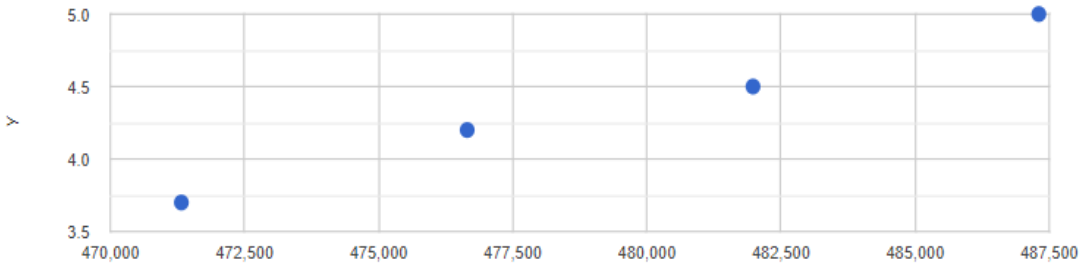

Figure 6 Correlation distribution field

A rather high and direct linear dependence is visually determined between the factor feature x and the resulting feature Y. The regression coefficient b = 7.8840666766742E-5 shows the average change in the performance indicator (in units of measurement y) with an increase or decrease in the value of factor x per unit of its measurement. In this example, an increase of 1 unit in y increases by an average of 7.884066666766742E-5.

The coefficient a = -33.44 formally shows the predicted level of y, but only if x=0 is close to the sample values.

But if x=0 is far from the sample values of x, a literal interpretation can lead to false results, and even if the regression line describes the observed sample value quite accurately, there is no guarantee that it will also be so when extrapolating to the left or right.

By substituting the appropriate values of x into the regression equation, it is possible to determine the adjusted (predicted) values of the performance indicator y(x) for each observation. The relationship between y and x determines the sign of the regression coefficient b (if > 0 - direct relationship, otherwise - inverse). The relationship is direct in this example. The study shows that distribution centres are an important sector of Kazakhstan's economy. A large number of distribution centres, their high productivity, and significant economic potential confirm the importance of continued development of this industry in the future. It has also been proven that the relationship between the need to increase the number of distribution centres is directly proportional to the growth in the e-retail trade volume.

5 Discussion

The conducted analysis illustrates the steady growth of the need to extend wholesale distribution centres, especially in large cities, including through the increase in retail sales in the area of e-commerce. This research substantiates such a relationship. In a developing economy, the creation of efficient distribution centres is of great importance. Having a well-planned distribution centre becomes incredibly important, as companies seek to expand into global markets. The situation with distribution centres in Kazakhstan is diverse and changing. At the same time, there are prospects for the development of this sector on the local market. However, if the matter is about the influence of the availability of infrastructure in the municipality, the availability of an airport, port or railway station in the city has a positive effect on the number of stations within the municipality and a positive effect on the number of facilities [24]. The coefficients in the study [25] show that if a municipality has a port, the probability of having more warehouses is higher than if the municipality has an airport or a railway station or a train station. And we did not examine such factors in our analysis, so the absence of the infrastructure factor in our study can be considered an element of limitation.

The factor of location, influence of the ecosystem is investigated in most studies [26]. The researchers [27] propose a complex model that takes into account the total emissions and the costs of disposal of emissions into the atmosphere. A study of the relationship between the increase in domestic e-commerce and the need for increased distribution centres is considered in the context of cost reduction [28] and does not specifically address the closeness of correlation.

The difference between our study and the existing ones is the application of the methodology. For example, the qualitative method includes the method of analysis of hierarchies, expert selection, the method of comparative analysis and fuzzy evaluation [29]. These methods can partially solve the research problem but contain some subjective factors. Quantitative methods include the gravity method, mixed integer programming, and two-level programming. Heuristic optimizations [30], such as the genetic algorithm and the tabu algorithm, are widely used in the complex optimization combined problem, which provides a new vision for the problem of increasing the number of distribution centres [31]. Summing up, it should be noted that the delivery of goods from the place of production is accompanied by large costs for the enterprise, and consumers wait a long time for the goods [32,33]. It is important to note that distribution logistics centres are highly efficient. The introduction of such centres ensures the continuous movement of goods, strengthening the connection between suppliers and end consumers.

6 Conclusions

Distribution centres are an integral part of the success of any business because they are an important link between producers and consumers. Without them, it would be difficult for enterprises to maintain adequate stocks and deliver products to consumers in a timely manner. The success of distribution centres is vital to the entire supply chain. This determines the relevance of the chosen research issue. The state of distribution centres in Kazakhstan can be characterized as developing. The introduction of new technologies and innovations, combined with favourable market conditions and political support, creates the basis for the development of reliable distribution centres that can increase the efficiency of logistics and contribute to the stable economic development of Kazakhstan.

The conducted research, based on the dynamics of cargo transportation by all modes of transport and the dynamics of retail trade growth, indicates an average growth of 10.5% in 2023 only for January-April, compared to the same period in 2022. Achieving the greatest efficiency requires the creation of logistics trade and distribution centres. The main idea of the organization of logistics centres in intra-city logistics is to connect a certain number of commodity flows entering the city before the city border and create effective forms of distribution through purposeful cooperation of all participants in the movement of goods. A strong direct correlation between the growth of e-commerce volume and the need to increase the number of distribution centres (correlation coefficient 0.995) is also proven.

It was established that distribution centres are a strategically important branch of Kazakhstan's economy and they need to be modernized and combined into wholesale distribution centres or new wholesale distribution canters shall be created. The development of this sector will contribute to the increase in the import and export of goods, as well as the improvement of the transport infrastructure, and further research is possible in this field. The introduction of incentive measures and innovative technologies will contribute to the development and growth of the distribution centre sector in Kazakhstan in accordance with international standards.

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Utilization of the intersection of ABC and XYZ analysis in stock planning in the warehouse by Covid period
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Utilization of the intersection of ABC and XYZ analysis in stock planning in the warehouse by Covid period

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Keywords: mobility, warehouse, stock planning.
Abstract: The aim of this article is to find the most appropriate inventory storage strategies in a new warehouse according to the Covid period. Based on the company's analysis and preferences, we have concluded that the most suitable inventory storage strategy will be ABC, XYZ and penetration analysis according to which the inventory will be produced to the company's warehouse. The result of the paper is the intersection of these analyses. Based on the penetration analysis, we found that AAXX group has 27% of the product items. The CXX group of manufactured items has a high turnover, but accounts for only 1% of the total items. The AA category has a low turnover but accounts for only 0.63% of the product items. As a result of the penetration analysis, we concluded that the categories AAXX, AAX, AXX, AX and BXX are suitable to be produced in large quantity in stock. For categories AAY, AY, BX and BY, it is recommended to plan the production of items for stock with caution and not to produce them in such large quantities. The regularity of the analysis of these methods is very important. The intersection of ABC and XYZ analyses indicates the regularity of applying these methods due to the existence of excess or non-replenishable stocks.

1 Introduction

The Group's systems within the company are the same worldwide, but each subsidiary can set them up according to its own requirements, as the systems offer several possible strategies. Each process can be carried out in several ways, so it is up to each branch to decide how it achieves the result, which is always the same. In this thesis, the commonly used ABC and XYZ analysis methods and their interpenetrations have been used. These methods were implemented on the stock data with some variations as several categories were used due to the large volume of material in large volumes. Based on the methods used in this way, it will be possible to categorize the different items in the company's warehouse differently. However, the use of these methods must be repeated in view of the changing product range in the company in terms of customer interest. In order not to create 'dead stock' in the warehouse by meaningless ordering for production, which would be easily available to the warehousemen and would not be of interest to the customer. The work also results in less frequent application of ABC and XYZ intersection analysis, which results in better use of handling equipment and there will be fewer empty paths for items that are stored in inappropriate locations. It all depends on which practices are more acceptable for a given country.

2 Literature review

Most distribution centres use simple activity-based classification (ABC) as a method of managing the classification of warehouse work, which can lead to increased operating and warehousing costs or a reduction in the efficiency of the circulation of goods. In addition, many studies in recent years have focused on solving ABC classification problems using a multi-criteria concept, method, or model; however, limitations can be found in these studies.

In the article [1], the authors found that with the help of the tool of dynamic systems it is possible to evaluate the effect generated by the project implementation with regard to the variables that directly and indirectly affect the cash flow of the examined company. Through the performed simulation, it can be stated that the warehouse management project increased the company's cash flow over a period of five years. However, the results are only valid if top management agrees to strengthen employee training processes and greater investment in technologies that enable faster and more efficient logistics processes.

Safety is one of the key aspects of the successful transport of cargo. In the case of road transport, the dynamics of a vehicle during normal events such as braking, steering, and evasive manoeuvre [2]. Safety is directly linked to the state of the infrastructure. How infrastructure affects transport performance can be seen in this case study [3].

The authors found that the ABC / XYZ analysis helps to improve the inventory management system in the supply chain, where proper inventory management is lacking. Monthly data for one year are collected and supplemented by primary data obtained through direct observation and discussion with the company's management. ABC, XYZ

and ABC / XYZ matrix analyses were performed to determine the items to consider when implementing Kanban. The analysis shows that the Kanban system can improve inventory costs by about 75% [4-7].

Proposes an analysis of the ABC-XYZ type modified with the observed deficit of goods. An illustrative example shows that the classical ABC-XYZ algorithm underestimates the value of goods when a deficit was observed; the magnitude of the coefficient of variation is also underestimated. The new method corrects this bias and recalculates the total gain and the coefficient of variation [8,9].

Inventory classification requires the use of several criteria to manage different inventory management functions. In this study [10], a new classification algorithm called the FNS (functional, normal and small) algorithm is developed, which combines the classic ABC classification with a new grouping strategy. In their study, the ABC classification method is enriched and combined with the proposed FNS algorithm to create nine different inventory classes. To achieve this goal, the classic ABC classification method is integrated with expert systems, clustering, and fuzzy logic methods [11].

This article [12] demonstrates how to classify inventory items using the TOPSIS model ("Order Preference Technique by Similarity to Ideal Solution"). The case study considered parameters such as unit costs, delivery time, consumption rate, etc. Using TOPSIS, the items are classified into categories A, B and C. The suitability, practicality, and effectiveness of the TOPSIS method used in the ABC classification were assessed using the analysis of variance (ANOVA) technique. A simulation model was used to compare the proposed model with the model of the traditional ABC classification technique.

The goal of inventory management is to decide on the appropriate level of inventory. In practice, it is not possible to check all stocks with equal attention. The most widely used inventory system is the ABC classification system. The ABC-FC authors' approach in Article [13] is implemented based on the required data. The results of their study show that 59 items are identified as a very important group, 69 items as an important group and the remaining 64 items as an unimportant group. Comparing the ABC-FC results with the original data, they found that their ABC-FC analysis showed high classification accuracy.

The aim of this paper [14] is to propose a regression approach to obtain a set of weights for ABC multicriteria inventory analysis that differ according to classification criteria but are common to all inventory items and follow a predetermined descending ordering scheme given the relative importance of classification criteria.

These documents propose a new approach to the ABC classification, which includes a non-compensatory aggregation procedure based on the ELECTRE III simplified method for calculating the score of each inventory item. The non-compensatory aggregation scheme means that an item's poor score in some important criteria cannot be compensated by its high performance in other criteria. A comparative study carried out on two actual data sets shows that the classification of the items produced by their proposed approach produced the lowest value of inventory costs among the items produced by all the classification models tested [14,15].

To bridge the gap that arises in the effective way of classifying inventory items into ABC analysis classes, articles has been created that proposes a model to adapt to the possibility of incorrect classification in the information. The maximum probability method is used to estimate the parameters in the model. The proposed method is verified by simulated and real data sets. The results show that the proposed method performs better in terms of classification accuracy and can learn the classification rules of experts from the training set and use them to classify new items [16,17].

These papers present a new approach to solving the problem of multicriteria classification of ABC stocks using stochastic multicriteria acceptability analysis. All possible preferences between the evaluation criteria were considered. Due to the fact that even with a certain preference, it is difficult to reach a group consensus on the exact values of the weights together with each criterion, they calculated the preference-specific intervals for each preference and then formulated a stochastic decision problem [18-20].

Authors in these papers describes a differentiated inventory management model of the ABC-XYZ classification matrix in relation to the inventory of a commercial enterprise. Inventory management is a very current topic, as the company has several branches, co-operates with many suppliers and the range of office supplies includes more than 30,000 items. The ABC-XYZ stock analysis of this business allowed them to identify inventory optimization strategies and identify groups that should be removed from the product range and, conversely, should be available in stock due to constant demand [21,22].

The issue of assortment optimization, whether in commercial companies or warehouses, is relatively topical. These papers show the analysis performed using the ABC - XYZ matrix of a specific product group and suggests possible optimization pathways [23,24].

A lot of authors discuss the multi-criteria ABC inventory classification and the methodology for standardizing each criterion and its weight in the classification. The weight for each criterion is based on a simple exponential assignment of smoothing weights. Including the weight for each criterion and normalizing the data, a score is obtained for each item and classification is performed based on the normalized score. This process of standardizing criteria and weights is easy for inventory managers to under-stand in practice [25-29].

Inventory management (IMP) procedures predominate in the organization and control of inventory in a company. The aim of these studies is to measure the performance of companies by determining the impact of distribution

turnover and inventory automation on competitive strength and operational efficiency. The study concludes that IMP has a significant impact on the company's performance and also contributes to the existing body of knowledge by helping inventory management professionals in the manufacturing industry [30-32].

3 Material and methods

Some countries have old WMS, e.g., Romania does not yet have a radio frequency system in place, so they are working in an off-line version. This means that before the start of the change, the warehouse handler receives a printed paper from the team leader, on which he has listed the codes of the products and the racking or pallet positions that need to be handled. The warehouse manipulator gradually marks the work performed and then hands over this paper to the team leader, who records these movements into the system. This way of working is much slower than the online system, where each warehouse handler has his own reader, with which he scans barcodes and the changes made are immediately visible in the system. Also, other small regional warehouses e.g., in Portugal, Spain or southern Italy may have the old system. Currently, four versions of this system are possible: old paper, old radio frequency, new paper and new radio frequency version. The analysed warehouse in Považská Bystrica uses the highest version of the system, i.e., a new radio frequency version. The new system will be gradually introduced in all branches, but it is proceeding from the largest plants.

Thus, the system provides some variability, but only in some things. As for customer requirements, they are centralized and cannot be changed, we can only adjust individual processes.

Another difference may be the different age requirements of the products. While in some countries, for example to Saudi Arabia, it is possible to ship only those products that are not older than half a year, within Europe there is a common requirement for products to be two years old [33,34]. As for specific customers this limit is set at nine months. If the products exceed the maximum permissible age for the customer, even by only one day, it is not possible to ship them, no exception is allowed here. Subsequently, these products are blocked in the system and can be sold, for example, to another country, where the sensitivity for the age of the products is not so high.

We can also compare prices for renting warehouse space in Slovakia and abroad. For this comparison, we chose Germany because the company's headquarters and central warehouse are located here. The company tries to have warehouse space under its direction, but it is not always possible, such as a warehouse in Považská Bystrica. The amount of rent for this warehouse is 3 €/month/m^2. The amount of rent for warehouse space in Germany as well as in Slovakia depends on several factors, e.g. from location, warehouse equipment, rental period, etc. If we take, for example, the city of Munich, we find warehouses whose rental amount ranges from 3 €/month/m^2 to 8 €/month /m^2 [35].

Method ABC analysis using to products a storage area of company

This analysis categorizes individual products stocks according to the article number parameter. This parameter was chosen because it best describes the nature of the problem. All tires for trucks and cars accepted into the warehouse in Považská Bystrica in the monitored period were included in the analysis. In this analysis, the individual items were classified into four categories, namely: AA, A, B, C. These categories were chosen because they correspond best to the production volume.

In order to compile this analysis, it was first necessary to modify the data so that it was possible to work with them. We worked with the file, which contained data on the number of the article, the number of articles and the number of products received for storage in a given month, their size, brand and other information. For the purposes of this analysis, data on the article number and the number of products received were sufficient.

Initially, it was necessary to recalculate each item from each piece to the number of pallets by month for both types of pallets. This is necessary because when designing the warehouse, we are not interested in the number of stored products, but the number of stored pallets. In this section, we worked with the "stock" and "number of products per pallet" files. Here it was necessary to combine these two files and, using the VLOOKUP function in Excel, to assign to each article the number of products on one pallet.

After knowing how many tires of a given article were on one pallet and how many of these tires were in stock, it was easy to calculate how many pallets of each article were in stock for a given period.

And therefore (1):

$$\textbf{number of pallets} = \textbf{number of stocks} / \textbf{number of tires per pallet} \quad (1)$$

We have rounded the result down to the whole number, because the number of stored pallets is always an integer and the rest of the tires, with which it is no longer possible to fill the entire pallet, should be stored on shelves as fractional pallets.

In the calculations, it was necessary to distinguish two types of pallets: OP1 and KSP. These pallets differ only in internal dimensions. While KSP pallets are CMR pallets, they have a less robust construction than OP1 pallets, which are pallets still used by Matador. When designing a warehouse, it will not be a problem that there are two different types of pallets, because the external dimensions have both types the same and will therefore be able to be stacked on top of each other. The only disadvantage is that the OP1 pallets have slightly smaller internal dimensions due to their more robust construction and are there-fore mainly used for storing car products. However, this is not the rule, we will also find several types of truck tires stored in them. On the contrary, truck products are mainly stored in KSP pallets. CMR therefore had to create its own name for the pallets used in one company in order to be able to

distinguish them in the system from the KSP pallets given by the headquarters, as a different number of products would fit in each. We worked with a total of 1 577 articles to compile the analysis, with the total number of products to be included being 9 906 460.

The following table (Table 1) shows, by way of example, the conversion of several items from pieces to the number of pallets.

Table 1 Conversion of articles to the number of pallets [authors]

Article	Pallet	Number of tires	Number of pieces per pallet	Number of pallets	Rounded
3410270000	OP1	325	50	6.50	6.00
3410560000	OP1	373	32	11.66	11.00
3410890000	OP1	268	32	8.38	8.00
3410990000	OP1	210	32	6.56	6.00
3411110000	OP1	573	60	9.55	9.00
4120640000	KSP	266	18	14.78	14.00
4120690000	KSP	887	22	40.32	40.00
4220490000	KSP	143	18	7.94	7.00
4220580000	KSP	1 282	22	58.27	58.00
4220760000	KSP	78	18	4.33	4.00
3413060000	OP1	432	36	12.00	12.00
3420220000	OP1	5	50	0.10	0.00
3420650000	OP1	245	60	4.08	4.00
3420940000	OP1	163	50	3.26	3.00
3434880000	OP1	59	60	0.98	0.00
3435130000	OP1	160	32	5.00	5.00
3435140000	OP1	291	60	4.85	4.00
3435200000	OP1	690	36	19.17	19.00
3435330000	OP1	486	32	15.19	15.00
5251380000	KSP	201	8	25.13	25.00
5251670000	KSP	267	8	33.38	33.00
5251680000	KSP	371	8	46.38	46.00
5304200000	KSP	227	10	22.70	22.00
5304210000	KSP	164	10	16.40	16.00

Subsequently, the number of pallets received was sorted in descending order from the largest to the smallest, and the cumulative percentages were calculated. Based on the accumulated percentages, we gradually assigned individual categories to the items (Table 2). The percentage limits set for each category were set by the company, based on their experience in planning and organizing warehouses.

Table 2 Categorization of articles [authors]

Article	Number of pallets	Pallets received in %	Cumulated pcs	Cumulated %	Category
5320820000	19 502	5.3890	19 502	5.3890	AA
3561010000	1 537	04257	70 596	19.5077	
15810370000	802	0.2216	121 588	33.5983	
3629830000	508	0.1404	179 648	49.6420	
4703130000	506	0.1398	180 154	49.7818	A
3450020000	367	0.1014	222 668	61.5297	
15545650000	324	0.0895	235 335	65.0300	
4512240000	299	0.0826	242 497	67.0090	
3585310000	299	0.0826	242 796	67.0917	B
15506440000	240	0.0663	266 780	73.7191	
4515600000	220	0.0608	274 535	75.8621	
3553340000	168	0.0464	296 871	82.0342	
5320860000	143	0.0395	308 916	85.3626	
4516800000	143	0.0395	309 059	85.4021	C
15810710000	124	0.0343	318 360	87.9722	
3451320000	106	0.0293	327 139	90.3981	
4520570000	44	0.0122	354 103	97.8491	
3446250000	1	0.0003	361 887	100.0000	
⋮	⋮	⋮			
Total sum	361 887	100.00			

In Table 3, the resulting ABC analysis is performed, where the percentage of articles, the number of articles, the number of pallets received and the percentage of received pal-lets are given separately for each category.

It is clear from the table that there are a small number of articles in groups AA and A, but if we look at the number of pallets received, only group AA alone includes almost the same number of pallets as the other three groups combined. The largest representation of articles is in the last group and therefore in group C. There are up to 937 articles, but after conversion to pallets we see that there are only 52 971 (Figure 1). When designing a warehouse, it will be necessary to take this into account and place this group furthest from the picking zone. This will also be taken into account when creating pallet blocks. In terms of per-centage revenue, it can be seen that almost half of all pallets received per year are in the AA category, which should be the most important and most beneficial for the company.

Table 3 ABC analysis [authors]

Category	% of articles	Number of articles	Number of pallets received	% of received pallets
AA	10.1	160	179 648	49.6
A	10.1	160	62 849	17.4
B	20.3	320	66 419	18.4
C	59.4	937	52 971	14.6
SUM	100.0	1 577	361 887	100.0

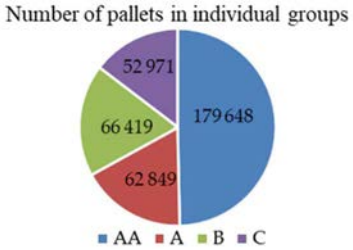

Figure 1 Frequency in individual groups [authors]

It may seem that in group A there is a small number of received pallets compared to group B, but there are half as many items in it and thus a larger storage block can be created without the problem of handling a pallet with a particular item. So it does not hap-pen that the handler will have to disassemble entire stacks of pallets in order to get to one particular pallet. Another advantage is that this saves space, as it will not be necessary to create so many handling aisles.

For the analysis to remain effective, it must be evaluated regularly, as the level of stocks is constantly changing, and therefore the placement of items within categories will also change.

Warehouse layout

When we had recalculated all the items for the number of pallets, we made a clear table where we arranged the categories, months and number of pallets received. This sorting was necessary to see how many pallets from a particular category are accepted into the warehouse each month and to be able to further adjust the layout of the entire warehouse accordingly (Table 4). Another important step was to determine the average, minimum and maximum stock values for each category.

Table 4 Overview of categories by months[authors]

Category→ Month↓	AA	A	B	C	Sum	Average
01.10.2018	10 017	3 798	4 667	7 237	25 719	6 430
01.11.2018	10 502	4 108	4 357	5 940	24 907	6 227
01.12.2018	9 718	3 673	4 057	5 935	23 383	5 846
01.01.2019	8 933	3 975	4 672	6 421	24 001	6 000
01.02.2019	7 961	3 513	4 185	6 402	22 061	5 515
01.03.2019	7 399	3 480	3 849	5 431	20 204	540
01.04.2019	7 290	3 847	4 464	5 851	21 452	5 363
01.05.2019	8 339	3 994	4 400	5 869	22 206	5 651
01.06.2019	9 501	4 179	4 947	6 519	25 146	6 287
01.07.2019	11 248	4 541	5 660	7 673	29 122	7 281
01.08.2019	12 389	5 379	6 068	7 886	31 722	7 931
01.09.2019	8 408	3 941	5 049	6 872	24 270	6 068
01.10.2019	9 391	3 894	4 860	6 427	24 572	6 143
Sum	121 096	52 332	61 280	84 463	319 161	
Average	9 315	4 025	4 710	6 497		
MIN	7 290	3 480	3 849	5 431		
MAX	12 389	5 379	6 068	7 886		

Based on the previous table, the sizes of pallet blocks for individual zones were determined. The average number of pallets in the warehouse in individual categories and how many items are in the given category were important for us. The size of the zone is just in other words how many stacks of pallets will be in the zone. The number 6 in the calculation will mean the maximum possible number of pallets in the stack. We calculate it as follows (2):

number of stacks = number of pallets in a group / 6 (2)

Before we start calculating the number of stacks, it will be necessary to determine how many rows of pallets will be in the block (Table 5).

Table 5 Number of rows of pallets in a block [authors]

Category	AA	A	B	C
Number of rows of pallets in a block	5	4	2	1

Once we know how many rows of pallets will be in each block, we can proceed to the calculations of the number of stacks and then calculate how many blocks will be needed to be able to store all these pallets. In the calculations, we will again consider the average monthly number of pallets in each category.

number of blocks = number of stacks / number of rows of pallets in a block (3)

Table 6 Calculation of the number of blocks and stacks [authors]

Category	Calculation	Number of stacks	Calculation	Number of blocks
AA	9 315 / 6	1 553	1 553 / 5	311
A	4 025 / 6	671	671 / 4	168
B	4 710 / 6	786	786 / 2	393
C	6 497 / 6	1 083	1 083 / 1	1 083
SUM		4 093		1 955

Table 6 shows that we will need 1 553 stacks to store average monthly AA stocks, which will be in 311 pallet blocks. It is necessary to store an average of 671 stacks of pallets in group A, which will be arranged in 168 blocks. There will be 786 stacks of pallets in group B and 1 083 stacks in group C.

Further calculation will be necessary to find out how much space we will need to store average stocks in each category (Table 7). As we know that the pallet dimensions 240 x 120 x 150 cm, i.e., one pallet occupies an area of 2.88 m^2, we can calculate what minimum area needs to be set aside for each category. The calculation will be as follows:

area size = number of stacks in the category * 2.88 m^2

Table 7 Required area for each category [authors]

Category	AA	A	B	C	Sum
Area needed to store average stocks (m^2)	4 472.64	1 932.48	2 263.68	3 119.04	11 787.84
Area needed to store maximum stocks (m^2)	5 947.20	2 581.92	2 912.64	3 785.28	15 227.04

Handling alleys

In general, the width of the aisle must be at least 40 cm wider than the widest dimension of the forklift trucks used in the warehouse or the largest width of the load handled in the warehouse. In the conditions of this warehouse, this would mean that the largest dimension of the forklift truck is 3.886 mm, in which case the width of the aisle would have to be at least 4.286 mm.

For our design, we will recalculate the ratio between the storage place and the aisles using a coefficient of 0.7, which means that there will be 0.7 pallets per 1 m2. The coefficient was obtained by calculating the average of the ratios between storage places and aisles in each category. These ratios are different because there is a different number of stacks in a row in each category. While there are up to 5 rows of pallets in category AA, there is only one row in category C. When we imagine in this category that we start to stack stacks of pallets from the wall, immediately after the first stack, an aisle must follow and again a stack of pallets. which, however, is already touching the back of another stack. In category AA, up to five stacks of pallets are stored in a row in our case, and only after these five stacks is an alley. So, the more rows of pallets we have behind us, the better the use of storage space. The coefficients for each category are as follows (3):

- AA: coefficient 0.9,
- A: coefficient 0.75,
- B: coefficient 0.60,
- C: coefficient 0.55.

This means that if we have a storage area of 34 539 m^2, we will calculate as follows:

34 539 m^2 * 0.7 = 24 177 m^2

From the calculation, we found that the area on which the pallets can be stored has a size of 24 177 m2, so the handling aisles will occupy an area of 10.362 m2. If we wanted to find out how many pallets can be stored in the warehouse at one time, we would divide the area designated for storage by the area occupied by one pallet, and thus:

24 177 m^2 / 2.88 m^2 = 8 394.79 pallets

It is clear from the calculation that it is possible to store 8 394 pallets in one layer in this warehouse at a time. However, if we made stacks out of all the pallets, we would multiply this number by six (maximum possible stack height) and we would get a result of 50.364 pallets.

Racks

In addition to the zoning of the warehouse according to categories AA, A, B and C, it will also be necessary to design a rack that is designed for partial pallets and is located at the picking zone. This rack is usually 1.5 times the number of articles. As there are 1 577 items in stock, the procedure will be as follows:

1 577 * 1.5 = 2 365.50 pallets.

For these racks, the maximum permitted height is five pallets on the rack. It will be necessary to store 2 366 pallets at the picking zone, when we divide it by the number 5 we get: 2 366 / 5 = 474 stacks. It will therefore be necessary to prepare 474 racks with 2 366 pallet places. The total area required for one rack position is 3.12 m^2. The area (Table 8) required for the rack is:

474 stack * 3.12 m^2 = 1 478.88 m^2

Table 8 Total warehouse area [authors]

Name	Area (m^2)
Total storage area	34 539
Net pallet storage area, of which:	24 177
- rack regal	1 478.88
Handling alleys	10 362
Administrative and technical premises	1 243

Method XYZ analysis using to products a storage area of the company

For a more comprehensive inventory classification, XYZ analysis was also added as another method for processing the warehouse design. This analysis, unlike the ABC analysis, does not look at the number of stocks, but at their turnover. As with the ABC analysis, we considered all items. In this case, we worked with the same inventory. In this case, the classical XYZ analysis was extended to four categories, namely XX, X, Y and Z.

The first step was to determine the average annual stock of each item. This stock ranged from 1 to 10 846 item per year. Subsequently, we assigned exports to each item in addition to inventory. Once the average stock was quantified and matched with exports, the turnover time and turnover of the articles could be calculated.

Turnover time was calculated first. Turnover time means the average number of days during which stocks are tied up in the company until they are used up or, in our case, sold. In general, the best possible turnaround time for a company is the lowest time. It is calculated according to the formula (4):

turnover time = (average stock * 365) / export (4)

In this case, we got values from 0.62 to 160.198 days. At these extreme values, we find items that were produced, stored, and not removed at all or only a small part was removed during the period under review. These are a few dozen items that are characterized by the fact that the company ordered a new dimension of items, but when they were made, they found that there was not much demand for them and thus remained in stock.

If we know how many days the average turnover time of individual items lasted, we can continue by quantifying the turnover, which means how many times a year the company's stocks turn. We will use the formula for this (5):

turnover = export / average stock (5)

Turnover in our calculations ranges between 0 and 592 times a year. Again, there are extremes created because the items were stored before the period under review, there is a minimum of stocks, but many of them have been released from the warehouse. The following table (Table 9) exemplifies a few items recalculated according to turnaround time and turnover.

Table 9 Turnaround time and turnaround [authors]

Article	Average stock in pcs	Export in pcs	Turnover time in days	Turnover
15496930000	10 846.00	39 575	100.03	3.65
15852680000	7 381.94	111 000	24.27	15.04
4733570000	6 478.62	72 457	32.64	11.18
4511770000	6 334.29	10 640	217.29	1.68
3539290000	5 292.00	103 651	18.64	19.59
4515570000	5 055.29	5 036	366.40	1.00
15810490000	4 869.00	46 002	38.63	9.45
15808960000	4 721.08	46 347	37.18	9.82
4280470000	4 705.77	40 725	42.18	8.65
3567930000	4 496.69	26 449	62.05	5.88
4512000000	4 401.43	15 458	103.93	3.51
15853410000	4 334.33	43 780	36.14	10.10
3732070000	4 314.00	63 145	24.94	14.64
15852830000	4 312.83	68 548	22.96	15.89
4511980000	4 297.00	13 348	117.50	3.11
3732350000	3 534.73	24 389	52.90	6.90
3575980000	3 499.08	13 735	92.99	3.93
3561010000	3 406.69	65 312	19.04	19.17
15810220000	3 387.89	25 424	48.64	7.50
4514920000	3 367.00	1 000	1228.96	0.30
15852630000	3 340.67	76 708	15.90	22.96
15810120000	3 305.38	33 166	36.38	10.03
3592480000	3 216.54	2 654	442.36	0.83
⋮	⋮	⋮	⋮	⋮

After consultation with the company, the boundaries of the individual categories were set as follows:

- XX: 15%,
- X: 15%,
- Y: 30%,
- Z: 40%.

These limits were determined in the same way as in the ABC analysis according to the number of articles. Thus, for category XX, 15% was multiplied by the total number of articles.

To be able to assign a category to each article, it was necessary to rank the turnover from the largest to the smallest and then categories could be assigned, with the first 15% of articles falling into category XX, another 15% into category X, the following 30% into category Y and the remaining 40% to category Z. Turnover values are by category in the following ranges:

- XX - from 17.03 to 592 times a year,
- X - from 11.36 to 17.02 times a year,
- Y - from 5.35 to 11.28 times a year,
- Z - from 0 to 5.34 times a year.

In the end, we made a clear table (Table 10), where the individual groups are converted to the number of articles, the number of items and the percentage expression of the category on the total number of tires.

Table 10 Clear table of articles

Category	% of articles	Number of articles	Number of items exported	% of export
XX	15	256	3 928 527	40
X	15	256	2 545 939	26
Y	30	510	2 580 739	26
Z	40	682	851 543	8
	100.00	1,704	9 906 748	100.00

It can be seen from the resulting table that up to 40% of all exported items belong to the category with the highest turnover, i.e., to category XX. Items that fall into this category need to be placed near the picking zone as part of the stock distribution, as they will be picked much more often than items in groups X, Y or Z. This step will again increase the productivity of order picking. There are approximately the same number of exported items in categories X and Y, which are around 26%, but in terms of the number of articles, there are half as many articles in category X as in category Y. These articles can be described as medium speed. Within the warehouse, it is appropriate to place them outside the category XX. The last category Z is characterized by low turnover and consists of only 8% of all items that left the warehouse during the period under review (Figure 2). Items from this category are recommended to be placed deeper in the warehouse, as they will not be picked up as often as items from other categories.

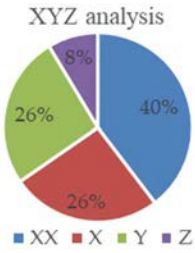

Figure 2 XYZ analysis [authors]

The purpose of this analysis was to point out the regularity of demand for specific articles. Like the previous analysis, this one should be re-evaluated on a regular basis in or-der to maintain storage efficiency.

4 Results and discussion

Application of ABC/XYZ analysis

ABC and XYZ analyzes are often used together in practice. These analyzes comple-ment each other and thus disseminate information on solved stocks. By combining them, we get more accurate information about how individual stocks behave and how they need to be approached. At the same time, we will find out whether items that are produced in large quantities really belong to high-turnover and, conversely, those that are produced in smaller quantities are low-turnover. We get a total of 16 categories that stocks can fall into, they are:

- AAXX, AAX, AAY, AAZ,
- AXX, AX, AY, AZ,
- BXX, BX, BY, BZ,
- CXX, CX, CY, CZ.

Using Excel, we combined the two analyzes and created two 4 x 4 matrices with the number of articles and the number of items in each group.

Table 11 ABC/XYZ number of articles [authors]

	AA	A	B	C	Sum
XX	81	61	60	48	250
X	36	52	93	76	257
Y	33	29	121	306	489
Z	10	18	46	507	581
Sum	160	160	320	937	1 577

Table 11 and Table 12 show the number of articles in each category. This table confirms the theory that articles that are produced in large quantities also have high consumption. Of course, there are also articles that fall into the AA category, i.e., they are produced in bulk, but their turnover is low, but it is only 0.63% of articles (Figure 3). It is recommended to produce as few pieces as possible in stock for these items, so that there is no demand for them. Most articles are in the CZ group, but if we look at Figure 3 below, we find that after calculating the number of items, it is only 5% that fall into this group.

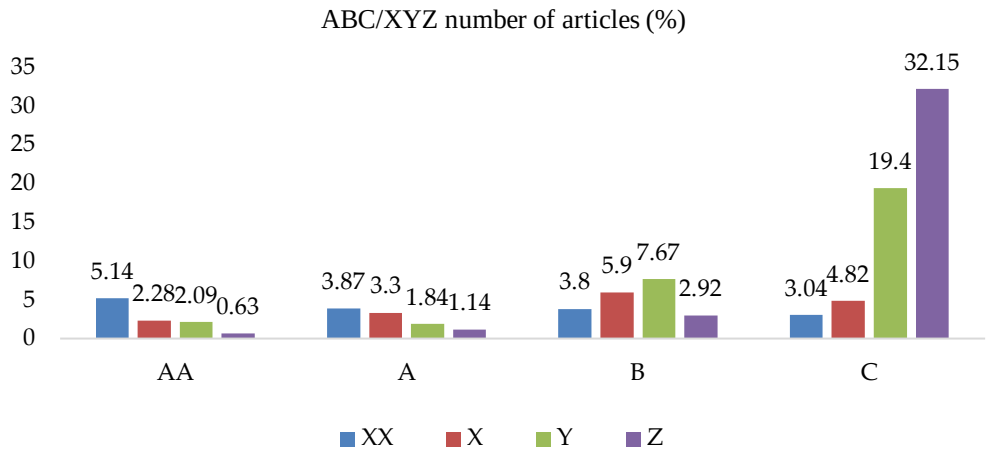

Figure 3 ABC/XYZ number of articles [authors]

Table 12 ABC/XYZ number of articles [authors]

	AA	A	B	C	Sum
XX	2,625,905	727,184	382,607	138,574	3,874,270
X	1,013,508	629,458	616,942	260,054	2,519,962
Y	751,844	371,124	680,063	681,227	2,484,258
Z	163,441	153,178	185,657	525,694	1,027,970
Sum	4,554,698	1,880,944	1,865,269	1,605,549	9,906,460

Also, in the case of conversion of articles to the total number of items, it was con-firmed that the most produced items have also the biggest turnover (Figure 4). The largest numbers of items are thus arranged around the diagonal.

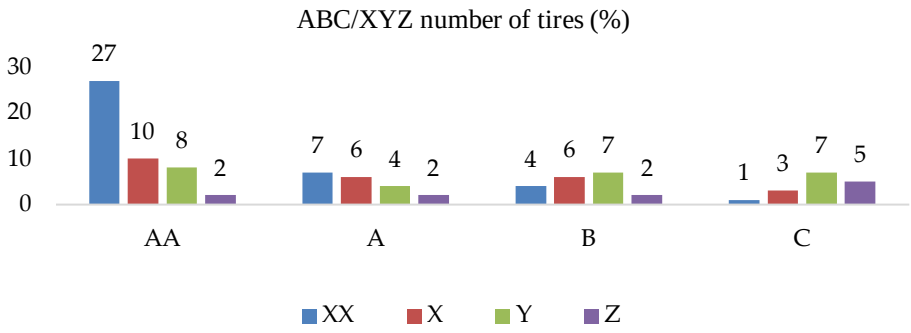

Figure 4 ABC/XYZ number of items [author]

The AAXX category represents up to 27% of the total number of items produced, which is the most of all categories. It is immediately followed by the AAX and AAY categories. In the case of category AAZ, consideration should be given to the need to produce items for stock. However, in this category, as mentioned above, there are items that have been ordered in large quantities by car companies and subsequently there has been no demand for them. The lowest percentage of items is in the CXX category, i.e. in the category where few items are produced but have a high turnover, but it is only 1% of the total number of items.

An article is currently in a certain category does not mean that it will be in the same category, e.g. in two years. This is due to the constant development of the market, hence the change in demand and the portfolio of company. That is why the regularity of analysing these methods is very important. Otherwise, items that are no longer in demand could still be in stock and placed as close as possible to the picking zone. As a result, they will unnecessarily take up space in the warehouse with other items that are in high demand. If the company adheres to the distribution of stocks according to these methods, it will be guaranteed an efficient method of storage.

5 Conclusion

The conclusion will be presented outputs of article and formulate the benefits of the proposal and any recommendations for companies.

This article was aimed at finding the most suitable strategies for storing stocks in new warehouse. This search was preceded by various analyzes of the warehouse, which is currently used in the company, but will soon be replaced by our proposed warehouse.

Based on these analyzes and the company's preferences, we have come to the conclu-sion that the most appropriate strategy for storing stocks will be ABC analysis. The dis-tribution of stocks according to this analysis will ensure that the items that are accepted into the warehouse in the largest numbers will be stored as close as possible to the picking zone and, conversely, the items produced in lower numbers will be placed deeper in the warehouse. Furthermore, this division will make it possible to reduce the ratio between the storage site and the handling aisles, so that in categories where many items are received but there is a low number of articles (category AA), we can make storage blocks where the ratio of handling aisles as in categories where many different items are received (category C), so it is not possible to create as large a storage block as in the first case. This is due to the fact that the handling of individual pallets would be more demanding and lengthy. If the pallet with the required item were stored, for example, only in the third row of pallets, there would be an unnecessary waste of time.

As another method, XYZ analysis was chosen, which had the task of providing more detailed information about the stocks, and thus to point out the regularity of demand for specific items. Its essence is the distribution of stocks according to turnover, i.e., according to how often specific items are released from the warehouse. In category XX, there are such types of items that are exported from the warehouse most often and are therefore best sold. There are 256 articles here. Also in category X there is the same number of articles, but al-ready a lower number of exported tires. Group Y includes items that have a medium ex-port frequency, and group Z includes items that are sold the least. From this analysis, we found that up to 40% of items belong to the high turnover group. Excluding extreme val-ues, items falling into this category are exported from the warehouse 17 to 52 times a year. Both categories X and Y account for 26% of items exports, so this is a medium turnover. The only difference between these categories is the number of articles. There are half as many articles in category Y as in category X. The last category accounts for only 8% of to-tal items exports, but there are 40% of all articles. It is therefore a low-turnover category.

At the end of the article, these two analyzes were combined to create a comprehensive overview inventories. From the result of this analysis, it is possible to recommend which items are suitable for production in larger quantities for stock and for which, on the con-trary, it is appropriate to minimize stocks. Categories AAXX, AAX, AXX, AX and BXX can be included in the group for which it is appropriate to produce items in large quantities in stock. For categories AAY, AY, BX and BY, it is recommended that the planning of the production of items for stocks be done carefully and not produced in such large quantities, because there are higher fluctuations in demand. For the remaining categories, it is rec-ommended to produce as few items as possible in stock, as they are the least stable in terms of demand. This analysis confirmed that the items produced in the largest numbers are also the most in demand. This is illustrated in particular by the AAXX category, which includes up to 27% of all items produced per year. The opposite was also confirmed, and thus that the items with the least turnover are also the least produced. This analysis can be helpful in production planning and demand forecasting.

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Mitigating data inaccuracy and supply chain challenges in Western Romania's automotive industry

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Keywords: data accuracy, operational performance, logistics, supply chain management.
Abstract: The purpose of this paper was to emphasize the importance of data accuracy within internal logistics systems and their extended influence on supply chains in automotive industry through 6-month multiple case studies conducted on 3 first tier original equipment manufacturers (OEM) based in Western Romania. The study investigates the most common causes of data inaccuracies among automotive suppliers and their approaches to reduce consequential supply chain issues and be more agile. Data collection and analysis revealed that main issues arise due to ordering quantities mismatching actual customer demand, a wide range of order lot sizes, lead times and delivery reliability concerns and the reluctance to shift away from mainstream cost-effectiveness and towards strategic added value thinking. These issues sourced significant other related operational challenges such as excessive inventory, short-term stockouts and subsequent express shipping services or product-related inconveniences (quality and capacity levels, contracted volumes and dedicated lines). The paper sources different logistics and supply chain strategies used by the 3 OEMs, their features and operational performance, as well as their overall effectiveness, which can be applied by other automotive industry suppliers to improve own results. Introducing more reliable real-time data collection tools and performance metrics has started hauling more focus towards solving these prevalent issues with some ongoing improvement projects showing up to 25% better results. For one of the 3 OEMs introducing a new warehouse management system has already sourced an overall quality increase (5 percentage points) due to a 60% higher utilization of its production equipment.

1 Introduction

The automotive industry is one of the most important industries worldwide, driving investments, employment and innovations throughout its highly competitive supply chains, both vertically and horizontally. Battery-electric vehicles (BEV) are the new trend (14.6% market share and an impressive 37% increase in sales, 2023) as car sales in the EU reached 10.5 million units (13.9% year-on-year increase) based on The European Automobile Manufacturers Association (ACEA) 2023 report. According to ACEA at EU level only the automotive industry sources, directly and indirectly, 13.8 million jobs (11.5% of EU manufacturing jobs and 6.1% of overall EU employment) in its 322-vehicle assembly, engine and battery production plants and is the leading investor in R&D with almost 60 billion euros (31% of total spending, 2022). Dacia and Ford are the pillars in Romania (13% of GDP, 20% of the manufacturing industry and 30% of exports, 2023), enabling around 230,000 specialized jobs within more than 500 suppliers across the country. Last year Automobile Dacia produced 322,086 units (2.3% year-on-year increase) in Mioveni, while Ford Otosan's Craiova plant made 190,964 units (2.2% year-on-year decrease). Nevertheless, their combined output exceeded half a million units (513,050 cars made in Romania) for the second year in a row (0.7% year-on-year increase). The longest highway in Romania (A1) lacks a 140 km connection between Pitesti and Sibiu (called "the Dacia highway") along the Olt Valley single carriageway (DN7) and there is currently no highway connection (120 km on the DN65 single carriageway) between Craiova and Pitesti (called "the Ford highway"). Dacia is market leader in Romania (33% share with 46,124 units sold in 2023), but both carmakers sell less than 10% of their volumes on the local market as most of their production is shipped to export destinations in the EU. Dacia ships more than 8,000 assembled cars (by truck and/or train) every week to its distribution centre (DC) in Valenton (France) by rail, the Port of Constanta (for transit towards non-EU destinations by sea) or Germany (delivery lead-time is 2-4 days by road). A further 600 trucks leave the International Logistic Network (ILN) from Mioveni with containers of CKD and SKD kits (representing two-thirds of the Automobile Dacia plant production output) to be assembled elsewhere in Renault Group plants (Africa, South America or Asia). Ford also ships 90% of its production abroad, most of it by train (70%) to Neuss, Germany and the rest via road (25%) and sea (only 5% is shipped through the port of Constanta). Up to 600 cars (by rail) leave from Craiova every day towards Ford dealerships throughout Western Europe via the Railport Arad intermodal terminal in Curtici (Romania-Hungary border).

A major share of the automotive supplier network is concentrated in Western Romania, where important multinational brands have set up and extended capacity in recent years and experience business growth [1]. Reduced product life cycles, engine downsizing, increasing prevalence of head-up displays (HUD) and the shift towards electric vehicles (EVs) all mean that carmakers have to balance out integrating innovative technologies [2]

fast whilst also being able to plan out an operational and competitive business unit [3,4]. A reliable and supporting supplier network is vital in such a challenging setting and its appropriate design (location, alternates and preferred selection) will determine the extent of a dependable and relevant data interchange system [5-8]. Adapted and appropriate logistic system choices (own/external warehouses, in-house logistics department/third-party logistics (3PL) externalizing and distribution centre (DC)/logistics service providers (LSP), etc.) will have a major effect on cost structures, delivery times and quality of data [9-13]. The overall performance of the company's internal organization, logistics (inbound, production scheduling, outbound) and supply chain management can be measured against its level of inventory [14,15]. This is because an actual JIT production strategy with properly balanced flows will not face inventory fluctuations that may cause excess amounts or, worse, stockouts and thus show the degree of its leanness [16,17].

The current study addresses the following research questions (RQ): what is the proper balance between process standardization and operational flexibility to achieve a competitive edge? (RQ1); what are the main contributing factors leading to data inaccuracies within a company's logistics department and its associated supply chain? (RQ2); what is the most efficient internal system for measuring and tracking real-time data and allowing for fast correction of errors within the production and logistics flows? (RQ3). This paper is the result of an ambitious research project carried out within the logistics departments of 3 multinational first-tier original equipment manufacturers (OEM) during a semester (total of 26 weeks) to assess the accuracy of specific data (inventory, forecasting and production) and quantify its influence on internal logistics KPIs and short loop supply chain (supplier-manufacturer-customer) performance.

2 Literature review

Data accuracy acts as a critical factor for significantly enhancing internal logistics performance and flow efficiency from inbound to outbound and within its corresponding supply chain. The dynamic of the automotive industry challenges OEMs and their supply chains to adapt and reconfigure processes to meet changing customer demands (downsizing, shift towards EVs, environmental policies) while in the meatime tackling supply chain disruptions, workforce shortages and integrated data management issues [18].

Agility is invaluable to maintain a competitive edge in a highly cost-effective oriented industry, especially since EVs have gained more and more market share on EU level in recent years [19]. Most automotive industry suppliers (OEMs, upper and lower tier suppliers) aspire to manage a reliable and accurate production system with room for innovation. However, finding the optimum balance between process standardization (to minimize in-house inaccuracies) and operational flexibility (to facilitate integrating new projects) is often daunting, especially in the short and medium term [20]. This is especially challenging since an EV's product life cycle (battery technology, charging infrastructure, government incentives) is still rather new in the automotive industry setting. In addition many OEMs still struggle with data silos (departments), outdated or rigid ERP systems and a lack of aggregate data integration on supply chain level hindering their ability to make inspired quality data-driven decisions. Employee induction, training and incentives are thus essential to promote responsible data handling practices and achieve higher data accuracy through gradual improvements based on experience.

Accuracy of data (relevant, real-time, synchronised and integrated) throughout internal logistics processes is critical for an effective operational performance in the long-term. The main contributing factors leading to data inaccuracies are the lack of standardization, human errors and scarce integration within the automotive supply chain [21]. On an individual level (automotive manufacturer or supplier), the most common sources of data discrepancies are manual entry errors, software inconsistencies and/or departmental silos which impact several internal decision-making processes (production planning, inventory levels, resource allocation). Focusing on relevant data, simplifying processes, understanding and explaining the role of data accuracy across departments will improve both production and logistics flows and improve inventory levels, resource allocation and operational performance [22].

Optimization is omnipresent in improvement projects concerning production and warehouse layout, logistic flows (inbound and outbound), inventory management and industry 4.0-specific tools implemented on the shop floor [23]. Well-designed intralogistics is not enough however. Automotive manufacturers also need a clear and reliable system for tracking data, allowing for the identification and correction of errors at their source (root cause). Data management structures, real-time relevant data sharing and ownership across departments can help improve data accuracy significantly. High-quality data is crucial for effective decision-making, allowing for a more targeted analysis and enables more relevant impact on overall productivity and operational performance [24].

3 Methodology

The methodology of the paper is based on a multiple case study conducted through 6-month research contracts (one was extended to a total duration of 11 months) within 3 first tier original equipment manufacturers (OEM) from Western Romania. Forecasting, planning & scheduling and performance management data from the last 5 years (2018-2022) was studied with relevant professionals of the 3 OEM's logistics departments. The final reports submitted upon completion of the carried out research are subject to non-disclosure agreements (NDA), as is most of the data collected within the 26 weeks of collaboration (2023).

Each of the OEMs has consented some sets of data to be published but not to the same extent therefore some sets are incomplete or have been slightly modified to ensure upholding all NDAs properly. Subsequent conclusions (partially) might not seem entirely relevant and partial limitations for each set of data are to be expected.

Production planning is based on relevant data (historical, projected volumes and actual customer orders) in order to compile a more reliable forecast, each of the 3 OEM's having different techniques. Projected volumes are increasing on a year-to-year basis in all 3 cases (7-12% on average for OEM 1, 3-8% for OEM 2 and 2-6% for OEM 3) thus the Holt-Winters exponential smoothing method was the most appropriate choice to process forecasting data accuracy. Holt-Winters exponential smoothing (or triple exponential smoothing) uses a smoothing factor (α), trend (β) and seasonality (γ) coefficients to improve forecast accuracy. The multiplicative method is more suitable for the automotive industry and was thus used in computations by all 3 OEMs. This is because the automotive industry exhibits seasonal patterns (new product launches, market volatility, high and lower sales seasons, holidays) and non-linear trends that are handled better by the multiplicative method since the simulations are also done for at least 1 full business year (and not short-term forecasting). After simulating different scenarios for the entire year, results were refined for shorter timespans as well (semester, trimester) upon request. Forecasted levels for each of the 26 weeks were based on projected volumes and smoothed exponentially with trend and seasonality (α=0.2-0.3; β=0.25-0.35; γ=0.4-0.6) by each of the 3 OEM's production planners. The exact smoothing factor (α), trend (β) and seasonality (γ) coefficients used by the OEMs are subject to the agreed and signed NDAs. The mixed team was tasked to provide a range of applicable solutions and improvement proposals by the end of the research contract. Our proposed approach was to target a smoother average throughout a complete business cycle (52 weeks) while also using 3-6 months shorter cycles to dynamically adjust outputs and increase accuracy. A slight added weight (α) was given to more recent data, but longer-term trend (β) was preferred with only marginal adjusting for the seasonal smoothing coefficient (γ) being necessary.

Actual forecasting accuracy results presented within the research paper are very limited (due to heterogeneous NDA terms of the 3 OEMs regarding consented datasets). Therefore, quantitative and qualitative data is aggregated and averaged for a total of 6-11 months. The (partial and ongoing) results of our individually submitted proposals combine practical solutions from each OEM's logistics professionals and theoretical methods from academic literature to attain optimum outcomes.

4 Results

All 3 multinational automotive industry OEMs are located in the Western region of Romania and are tier 1 supplier for all customer brand and model ranges. Nevertheless, despite certain similarities that are characteristic to the industry (main characteristics), the OEMs also have some differentiating features highlighted in Table 1.

Table 1 Overview of each OEM's characteristics

features		OEM 1	OEM 2	OEM 3
Production	type	standard	standard	standard
	technology	superior	above average	average
	volume	very high	high	high
Warehouse	own	yes	yes	yes
	external	yes	DC	yes
	management	in-house	in-house	outsourced
Data	ERP	new	standard	standard*
	KPIs	real-time*	real-time	real-time
	employees	mix*	mix	mix

The features that are compared across the OEMs are production (type, technology, volume), warehouse (own, external, management) and data (ERP, KPI and employees). In terms of production, all manufacture standard products involving industry innovations, fitted on any car brand or model (across all major car companies), as outlined in Table 1. There are technology differences, with OEM 3 having rather average technology-encompassed products, while the others have above-average (OEM 2) and superior outputs (OEM 1). Volumes are high for 2 of the 3 OEMs, as they each supply important amounts for their customers, whereas OEM 1's volumes are very high due to a larger product range (brand and model-specific requirements) delivered. Raw materials and components, as well as finished goods, are stored in both own and external warehouses, only OEM 2 not having an own external facility and using a distribution centre (DC) instead. Warehouse management is done in-house (OEM 1 and OEM 2), except for OEM 3 who has outsourced this activity to a third-party logistics (3PL) service provider. Data management is rather different, as only OEM 2 uses an industry standard enterprise resource planning (ERP) software tool. OEM 3 has added significant extra features (specific input-output reports) to enhance its data analysis to its existing ERP, whilst OEM 1 is currently transitioning the switch to a new ERP system and thus replacing the one it has previously been using for over a decade. All OEMs use systems that collect, show and monitor real-time data, only OEM 1 still having some processes where some data, decisions and reports have to be approved manually before being subsequently computed. There is a good balance of young and experienced employees in all 3 OEMs', with OEM 1 having more novice employees that need to be inducted and properly trained after termination of their internships in order to start handling some of the company's projects. OEM 1 has the highest volumes (new projects and facility extension are currently under way) and

is therefore more active in the hiring process than the other 2 analysed business units, where volumes are more stable.

Table 2 Overview of OEM 1's excess inventory per semester

Materials and components	Semester usage (units)	Monthly average (units)	Excess quantity (units)	Excess/semster usage (ratio)	Excess/monthly usage (ratio)
Supplier 1	151	25.16	518	3.43	20.58
Supplier 2	160	26.66	480	3.00	18.00
Supplier 3	191	31.83	512	2.68	16.08
Supplier 4	68	11.33	172	2.52	15.17
Supplier 5	150	25.00	300	2.00	12.00
Supplier 6	942	157.00	1404	1.49	8.94
Supplier 7	830	138.33	1109	1.33	8.01
Supplier 8	5320	886.66	6469	1.21	7.29
Supplier 9	640	106.66	765	1.19	7.17
Supplier 10	2190	365	-872	-0.39	-2.38
Overall average*	1762	293.66	4921	2.79	16.75

Table 2 outlines the forecasting, ordering and storage issues of OEM 1 in regard to some of its main raw materials and needed components for the manufacturing process. OEM 1's suppliers are mainly from Europe (Central and Eastern Europe) and Asia (East and Southeast Asia). The logistics department is based on a functional unit system where an employee fulfils a specialized role within small (3-5 members) or average teams (6-10 members) tasked with specific organizational functions. Each role has a high degree of autonomy, even interns or newly hired employees, and has at least one back up colleague who can temporarily stand in and take over corresponding tasks. Rising volumes (new projects, new products) increase the amount of orders each role has to process, regardless of the number of customers, product range, models and associated specific requirements, creating an unbalanced workload. The planning department has access to the company's forecast, but each planner (3 levels) decides what amount to actually order, being able to personally adjust the quantity ordered. More experienced planners will tend to add a small margin (up to 15%), whereas the younger and less experienced ones will tend to add up to 50% or even double the ordered amount in view of rising volumes, repetitive orders and long-terms contracted quantities. This choice will however increase the delivery lead time from the supplier and also bottleneck the warehouse, both own and external, its reception and storage capacity (recurring issue). Sometimes the ERP system shows a shortage of materials, but the truck is actually at the plant waiting to be unloaded (physically) with no available storage capacity within the own warehouse (waiting time: 4-8 hours), causing further delays in production. These issues can be found within the data shown in Table 2, as for the selection of 10 materials and components there is an average excess of inventory (2.79 semesters or 16.75 months) that would last for almost 3 semesters (18 months). The amount of inventory for some raw materials and components (suppliers 1-5) significantly exceeds monthly usage in production (12-20 months), congesting the warehouse, generating storage risks and causing imbalances. Materials from supplier 1 have an average monthly use of 25 units with inventory level being at 518 units (more than 20 times the required amount), whereas deliveries from supplier 10 are backlogged: 365 units/month (on average) are needed in production with a shortage level of 872 units (2.38 months), causing further scheduling delays. The other suppliers (6-9) have an inventory excess corresponding to 7-9 months, whilst other material surpluses, not shown in the table, range from 4-6 semesters using up unnecessary storage capacity, whilst others may be subject to further stockouts (e.g. supplier 10). These issues are then transferred to the shop floor, where it is very difficult to make up for the time lost with the reception, unloading and storage procedures and urgent and quick shipments are sometimes needed to compensate, as shown in Table 3. An online unloading schedule was introduced in 2023 for an improved planning of truck arrivals with dedicated time windows for each LSP with regular deliveries (and open slots for spot contractors), enabling better tracking of incoming materials (and confirmation of their reception) and after only 3 months using the system is mandatory for all LSPs arriving to unload at the warehouse gates.

Table 3 Overview of express shipment deliveries of OEM 1 towards main customers per semester

Express shipments	Deliveries (units)	Main reason	Price variation range (%)	Maximum amount (monetary units)	Total amount (monetary units)	Average price (monetary units)
Customer 1	17	constant	15-20%	23,806	106,346	6,255
Customer 2	6	spread	10-15%	11,200	59,727	9,954
Customer 3	14	peak	25-30%	11,200	38,346	2,739
Customer 4	6	spread	10-15%	2,570	12,032	2,005
Customer 5	11	shortage	25-40%	9,850	31,097	2,827
Overall average	10	constant	20-30%	11,761	49,509	2,475

Table 3 presents express shipments to some of OEM 1's customers within a semester (54 such deliveries in 6 months). While some of the urgent shipments are also due to external factors (peaks, shortages and unforeseen issues), most come about on a rather more regular basis due to similar reasons (customer 2 and 4) or are even constant occurrences (customer 1) tying up important amounts of working capital (almost 250,000 monetary units). Express deliveries for customer 4 have the lowest average prices (2,005 units) and lowest variation range (10-15%), the highest variation adding up to 28%. Customers 3 and 5 have similar average prices (2,739 and 2,827 units) and the highest average price variation ranges (up to 30-40%) with some shipments being rated 3-4 times higher than their average. Express deliveries to customer 2 are 4 times higher (9,954 units) than the overall average (2,475 units) and represent 24% of the total amount of shipments (247,548 units). With an average price of 6,255 units (2.5 times higher than the overall average), the 17 deliveries to customer 1 represent almost a third (31%) of all express shipments and almost half (43%) the total amount spent on the fastest form of dispatching.

This frequency of these quick shipments is also due to a range of new projects coming in and despite an extension of the manufacturing plant (new production area with a direct connection to the automated warehouse storage system) which is currently under way, it will not be completed until 2025, therefore production capacity is at full tilt, but also bottlenecked by unbalanced ordering levels. Overrating storage capacity (which has lost space due to shop floor being increased), also means backlogging production and not fully using manufacturing capabilities which in addition to the longer supplier lead times generate unproductive waiting times (longer production lead times, delayed loading of orders) and the risk of not delivering on time. Most customers are multinational carmakers located in Central Europe and have dedicated production lines (just in time (JIT) or just in sequence (JIS) type production systems), whereas the rest have their products manufactured in a flexible system (FMS), ranging from front-end to back-end processes. Regardless of brand and/or model range positioning, automotive manufacturing companies have high downtime costs, therefore idling or stopping production lines because of suppliers' delivery issues is not acceptable. Reliable suppliers with high service rates (orders delivered on time and in full, OTIF) are important all across the automotive supply chain, with special emphasis on higher tiers. OTIF puts pressure on all tiers and sometimes on-board couriers (OBC) are used to hand-carry certain components and parts in order to ensure on-time deliveries and avoid stopping a customer's production line.

Table 4 Overview of OEM 2's yearly production planning figures for a range of suppliers

Materials and components	Yearly usage (units)	Monthly average (units)	Minimum variation (%)	Maximum variation (%)	Average variation (%)
Supplier 1	2,000	166.66	10	70	29.17
Supplier 2	960	80	10	100	32.50
Supplier 3	522	43.50	17	100	27.59
Supplier 4	504	42	71	100	83.33
Supplier 5	336	28	14	100	47.62
Supplier 6	91	7.58	18	124	69.23
Supplier 7	1,000	83.33	20	100	63.33
Supplier 8	3,200	266.66	12	100	45.83
Supplier 9	432	36	0	150	58.33
Supplier 10	324	27	33	167	61.11
Overall average	936.9	78.07	21	111	51.80

Table 4 highlights OEM 2's production variation for a range of materials and components. Despite the OEM's high volumes, the average yearly variation was just above 50% for all material and component orders passed to the selected suppliers. Orders to suppliers 1-3 even had an average variation of around 30% throughout the year, a very decent accuracy level given the recent global supply chain challenges (Covid-19 pandemic, chip shortage, increased costs and price volatility). With 2 exceptions (suppliers 4 and 10) minimum variation is under 20%, whereas except the cases where no orders are placed (100% variation), maximum variations range between 60-90%, most cases however usually average between 30-50%. Two thirds of supplier orders match a batch-size ordering pattern, therefore our aggregated variation calculations show higher fluctuations and unpredictability than is actually the case in practice. Supplier 3 has the best forecasting, as their actual order variations only range between 17-24% throughout the entire year (increased predictability), whilst supplier 9 has 2 months with a perfect match between its forecasted orders and its actual passed order levels. Having a rather stable ordering pattern in the short loop supply chain (supplier-manufacturer-customer) with smaller fluctuations will improve the flow of goods and delivery reliability as well as reduce the risk of generating an upstream bullwhip effect (BE). Suppliers 9 and 10 also experience both a zero order situation, as well as a doubling of the order level throughout the year, thus yielding higher than average maximum variations (150% and 167%). To accommodate rising volumes OEM 2 decided to increase shop floor space on its premises instead of contracting an external warehouse and use a distribution centre (DC) closer to its customer locations. With no external warehouse to rely on in case of excess storage needs, OEM 2 relies on its forecasting and production planning to be accurate in order to deliver finished goods to its customers. The logistics department is divided into teams and each team focuses on specific customers and product ranges, as their orders will be divided among members based on the characteristics and complexity of the entire process (supplier orders, production lead times and delivery requirements). All in all, OEM 2's forecasting and planning in fairly reliable (forecasting accuracy has increased by 22% on a year-to-year basis, while production planning sourced a 17% improvement) with peaks and troughs being properly handled due to standard production levelling techniques. In addition, within the analysed business year (2022), only 3 express shipments were required due to a more balanced ordering-manufacturing cycle. The business unit's excellent logistics performance has been noticed by upper management and the facility will start managing the same range of services for one of the group's additional manufacturing plants starting 2024.

Table 5 Overview of OEM 2's delivery characteristics from the distribution centre towards end customers

Distribution center	Driving time (hours)	Pick-up day	Outsourced to	Expected service level (%)	Delivery type
Customer 1	58 min	Thursday	LSP1	95	JIT
	1h10min				
	3h28min				
Customer 2	3h46min	Wednesday	LSP2	85	JIT
Customer 3	4h03min	Friday	LSP3	98	JIS
Customer 4	7h40min	Wednesday and Friday	LSP1	95	JIT
Customer 5	21h19min	Monday	LSP 3 or LSP4	85	JIT
Overall average	7h44min	N/A	N/A	91.6	JIT

Table 5 presents the delivery characteristics for some of OEM 2's most important customers. OEM 2's DC is located at 15h52min driving time from Western Romania (border crossing times are not included). Border crossing (Romania-Hungary) for trucks includes waiting and document processing times at one of the 5 borders. Nadlac II is the most congested because it is the gateway to the A1 highway, where waiting times are 8-24 hours and can even sometime reach 48 hours. Bors II is an alternative, but also implies a 2 hour detour (A3 highway). Customer 1 has 3 possible locations for delivery from the distribution centre: delivery location 1 (DL1) has a 58 minute driving time, similar to DL2 (1h10min driving time), whereas DL3 is reached within 3h28min driving time. An average of 1h52min is thus needed with all 3 DLs expecting just in time delivery and a 95% service rate from LSP1 (the same LSP for all 3 DLs). Customer 4 and customer 1's 3 delivery locations are managed by the same logistic service provider (LSP1), only one other LSP (LSP3) having more than 1 customer to manage (customers 3 and 5). Customer 4 also has the second highest delivery lead time (7h40min) and has two alternative days (Wednesday and Friday) available for pick-up. Customers 2 and 5 have the lowest expected service level (85%) with customer 5 having two alternative LSPs due to its highest delivery lead time (21h19min). Customer 3 has the highest required service level (98%)

and is the only one to expect a Just-in-Sequence (JIS) delivery, all others using the typical automotive industry standard, the Just-in-Time (JIT) delivery.

Table 6 Overview of OEM 3' manufacturing process KPIs

Production data	Availability increase (%)	Performance target (%)	Performance level (%)	Quality level (%)	OEE (%)
Process 1	62	95	96	NDA	NDA
Process 2	66	95	94	NDA	NDA
Process 3	71	95	97	NDA	NDA
Process 4	46	95	87	NDA	NDA
Overall average	61.2	95	93.5	NDA	NDA

Table 6 presents the OEM 3's most important manufacturing processes and their overall performance after implementing an extended warehouse management (EWM) system within the first semester of 2023, as an extra add-on to its current ERP system. Actual quality levels and overall equipment effectiveness (OEE) measured values were subject to agreed NDA terms, only broad comments being consented for paper publishing. Despite an investment required to attach the EWM to the company's current ERP system, the return on investment (ROI) was attained sooner than expected. OEM 3 has both an own and external warehouse, but decided to focus on its core competence (manufacturing) and contract an LSP for part of its supporting logistics processes (warehouse and distribution management). Only the company's outbound logistics is outsourced (3PL), therefore an internal logistics department is required to support the production process (including planning, scheduling and levelling). Implementing the EWM has enabled better inventory accuracy, improved real-time process flow tracking and automatically-triggered replenishment (e-Kanban system). The increase in time availability (by an average of 61.2%) has also triggered a performance level increase of around 10% for all processes, most notably for Process 1 (96%) and Process 3 (97%), both above the set target, whereas Process 2 was just 1 percentage point below (94%). Process 4 experienced some unexpected technical issues and a temporary minor backlog which affected its rating (87%) within the current analysis. Nevertheless, after the issue was solved, the process had a similar output, matching the other processes' performance (within the same monitored timespan) therefore results should be more balanced towards the end of the business year (2023). The performance of each process is the average of the performance of the 3 shifts in the company per process, the morning and day shifts having slightly higher productivity figures (up to 3 percentage points higher) than the night shift (around 5 percentage points lower than the average of the first 2 shifts). Moreover a 5 percentage point quality level increase has been observed, as well as an OEE increase of 12 percentage points, key takeaways after only 6 months of implementation.

Table 7 Overview of OEM 3' warehousing performance KPIs

Warehousing data	Initial performance level (%)	Current Performance level (%)	Performance dynamic (%)	Performance target (%)	Measured vs. target performance level (%)
Process 1	NDA	NDA	+20	NDA	+4
Process 2	NDA	NDA	+16	NDA	+3
Process 3	NDA	NDA	+13	NDA	+2
Process 4	NDA	NDA	+10	NDA	0
Overall average	NDA	NDA	+14.75	NDA	+2.25

Table 7 outlines OEM 3's warehousing performance KPIs in terms of overall inventory accuracy for all inbound individual references and their main categories (raw materials, components, subassemblies, MRO) after implementing and connecting the extended warehouse management (EWM) system to the company's tracked KPIs. Integrated within the company's ERP system since early 2023, the system has improved overall reference accuracy for each of the 4 main processes (data is aggregated and averaged for a total of 11 months). Initial and current performance levels, as well as the set performance target values were subject to agreed NDA terms, only the resulting dynamic, variation and achieved result (measured vs. target performance level) were consented for paper publication. Process 1's overall inventory accuracy shows an increase of 20 percentage points (an increase of 26% when comparing current to initial performance) thus exceeding the target performance level by 4 percentage points. Data for Process 2 indicates similar results with an increase of 16 percentage points for

its current performance level (an increase of 19% from initial performance). Process 3 has the highest availability increase (see Table 6) which is also supported by its improved reference accuracy (13 percentage points increase of its performance level, 2 percentage points above target levels), an overall improvement of 16% in the last 11 months. Despite performing below average compared to the other processes in terms of availability (see Table 6), Process 4's warehousing results still met the target performance level. Data accuracy increased by 10 percentage points and showed an aggregated 12% increase in terms of a direct current to initial performance comparison. On an aggregate level, for all 4 processes, warehousing data shows an increase in current accuracy for all references of 14.75 percentage points (an increase of 18% when compared to initial performance) and an exceeded target performance level (2.25 percentage points on average and a 3% increase in relative figures). Actual results for the last month are not available (research contract ended), but they should fall within the same data range and confirm the aforementioned analysis. This was later confirmed by the OEM 3's logistics professionals who commented that "Results were as expected", validating the previous assumption (for business year 2023). High inventory accuracy (EWM), automatically-triggered replenishment (e-Kanban) and tracking operational performance and productivity in real-time (OEE) for OEM 3 meant an increase of the proportion of value added time (in total time), production efficiency and enabled a seamless flow of operations.

5 Discussion

The main objective of this research paper was to underline the relevance of data accuracy among tier suppliers from the automotive industry. Multiple-layered planning departments with unbalanced extra safety margins added up reduce the actual forecast accuracy and lead to excess inventory (up to 18 months) or stockouts (mismatched data in the system). Increased order quantities increase order lead times, impacting smooth operations flow (supplier delays, urgent order change regular scheduling, express shipments) and overall JIT production system. Express shipments are costly, but the cost of customer penalties for stopping their production line would significantly exceed the higher shipping rates. OEM 1 has good operational flexibility [25], but needs to enhance process standardization to improve cost-effectiveness, confirming that proper balance between the two is difficult to achieve in practice (RQ1). Nevertheless, the OEM 1's proven ability to integrate several new and challenging projects in the last 10 years have sourced multiple factory extensions in order to accommodate constantly growing volumes.

Customer-dedicated functional teams (within the logistics department) with complementary skills, collaborative spirit and shared accountability (both individual and team-based) are more adapted to specific project details and are more productive in problem-solving. Sharing information also leads to a better forecasting accuracy (lower overall variation compared to actual orders) and better overall production planning and scheduling (rare cases of express shipments, only 3 in the previous business year) with a reliable logistic system within the supply chain (DCs, LSPs and DLs delivering both JIT and JIS to automotive customers). OEM 2 has invested in training its employees to problem-solve and to then standardize knowledge within their groups and teams (RQ2). Understanding relevant data, simplifying processes and trusting each team member's role have significantly improved data accuracy across departments (both quantitative and qualitative), enabling smoother production and logistics flows and reduced inventory levels, boosting operational performance [26]. Stabilizing internal processes and procedures can also be a preventive response to an anticipated decline in business volumes on short or medium term, as suppliers tend to have primary data and first-hand evidence from the automotive sector.

Managing high volumes for automotive products with longer than average life cycles increases the importance of an efficient internal production process (proportion of added value) and seamless shop floor workflow. Shifting focus on core competence (manufacturing) means more resources are allocated to supporting activities of the production process (planning, operations, quality and continuous improvement) to increase productivity. Recognizing its strengths in manufacturing, OEM 3 strategically leveraged an external logistics provider (LSP) to manage a portion of its non-core outbound logistics processes (warehousing and distribution). This focus on core competencies streamlined internal operations (increase of time availability, performance levels and OEE) in support of the manufacturing process [27]. Implementing automated data tracking tools (EWM) also helps increase data reliability, inventory accuracy and the leanness of the overall production system. OEM 3 focused on improved operational performance (OEE) to maximize shop floor output [28] by improving data accuracy for inbound logistics (EWM) and outsourcing outbound logistics (distribution), indicating the value of process ownership (BPM) for automotive suppliers in order to source an approach that is most adapted to their specifics (RQ3). While improving operational performance might be a sign that OEM 3 is preparing to adapt to the anticipated automotive industry disruptions [29], it could also mean preparing for future growth on a more stable basis since its products have high aftermarket volumes as well (higher than OEM 1 and OEM 2).

This research delves deeper into the implications of data accuracy within an automotive manufacturer's internal logistics systems (forecasting, planning, and process management). Findings are representative, as existing research outlines the ripple effects of precise data [30, 31] within the supply chain, partially confirmed within this paper's results (efficiency and resilience), with additional

insights into a future automotive industry supply chain where agility and responsiveness will become equally important. The limitations of the paper come from the NDAs, limiting the presentation of actual results obtained (analytical completeness), affecting reproducibility and validity of presented findings. In addition, the case studies have a strong empirical component (very specific internal and external challenges), affecting replicability of data and results which are acknowledged.

6 Conclusions

The overall results confirm the existence of internal logistics performance issues within the 3 first tier OEMs from Western Romania. OEM 1's main logistics issues are inventory-related, as overestimating actual demand creates excessive inventory (up to 18 months for the analysed raw materials, components and parts), as well as increased supplier lead times and insufficient storage capacity, causing production delays. Subsequently adding arbitrary margins to forecasted levels of activity affect the reliability of the production scheduling and burdens storage capacity. Needing to manually approve certain data modifications within the company's ERP system (automatic option is available) yields unproductive waiting times and other interconnected teams or departments to use data that has not always been updated (ERP system showing a lack of material, but trucks waiting for hours to be unloaded in front of the warehouse, outlining the value of real time data. Furthermore, in addition to excess inventory (tied up working capital), several express shipments (worth almost 250,000 units) had to be contracted to prevent stopping customer production lines (carmakers) and bear huge penalties. Being agile and finding the right balance between process standardization (cost-efficiency) and integrating new projects (business opportunity) with current operations already running close to full capacity makes achieving overall competitiveness challenging (short and medium term). On the other hand investigating the possible outcomes of integrating advanced machine learning algorithms could be an insightful future research topic. Machine learning algorithms incorporate and handle real-time complex datasets (while also automating the process) and could source superior demand forecasting accuracy. Dynamic inventory optimization based on lead times could prove to be relevant, as adjusting inventory levels based on real-time lead time data and supplier performance fluctuations would also explore the feasibility of collaborative forecasting with the OEM's key suppliers. In terms of capacity management multi-tier storage options such as automated storage and retrieval systems (AS/RS) could significantly improve warehousing space utilization and should be a reliable option for dynamic capacity allocation based on product characteristics and demand patterns.

OEM 2's main challenge lies within accurate forecasting and balanced production planning schedule. With no external warehouse and a distribution centre almost 16 hours away from the plant (in addition to border Hungarian border crossing procedures), on time deliveries (OTIF) are mandatory to uphold car manufacturer service levels (JIT and JIS). Forecasting accuracy has improved by 22%, also enabling a more balanced production planning schedule for the second semester of 2023. Only 1 carmaker requires a 98% service level rate and JIS delivery, whilst the others mainly expect a 95% level and JIT delivery, the furthest away customer (22 hours from the DC) only imposing 85% rate on the service level. Future research topics could delve into inventory optimization methods that integrate lead times, transportation times and varying service level requirements (SLAs) of geographically dispersed customers. Multi-echelon inventory models with strategically placed buffer stocks closer to distant customers or vendor-managed inventory (VMI) programs with key suppliers could further increase OEM 2'delivery reliability. Dynamic production scheduling simulations could also explore and test the effectiveness of different scheduling strategies on on-time in-full (OTIF) performance (85% vs. 98%) for JIT/JIS deliveries and provide valuable insights.

OEM 3's outsources its outbound logistics therefore proper inbound logistics and production performance are needed to avoid shipping delays to its 3PL and end customers. The e-Kanban (integrated in the EWM) automatically reorders raw materials, components, subassemblies and MRO, thus supplying the production process in an appropriate pace and contributing to a seamless production flow. Overall inventory accuracy for inbound logistics (warehouse) has improved by more than 14 percentage points (more than 18% in relative terms) in only 11 months with 3 of the 4 process-related materials exceeding their target performance levels (by 2-4 percentage points). Implementation of the EWM has boosted the company's performance on all levels, as availability has increased by more than 60%, performance by around 10% (actual levels are within the set targets) and quality has risen by 5 percentage points. The OEE rating is thus 12 percentage points higher after implementing the new additional data management system, validating the relevance of an improved process flow performance monitoring system with real-time, reliable and accurate data integrated within a customized ERP system. Based on these results some possible further research areas could study advanced predictive analytics within the EWM's automatic replenishment module such as material criticality, lead time variability, potential cost implications of stockouts or excess inventory and suggest dynamic reorder points for critical materials (optimizing reorder points for e-Kanban). Furthermore, to strengthen process reliability and a seamless flow of goods (inbound and within the factory) real-time data analysis could be integrated within the current EWM. Analysing sensor data to predict equipment failures and scheduling preventive maintenance can be leveraged to minimize downtime and disruptions in the production flow would increase

availability to some extent. Increased machine availability would also enable real-time data to shift job priorities and optimize production sequencing, increase throughput of potential bottlenecks and resource allocation, ultimately maximizing Overall Equipment Effectiveness (OEE).

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Increasing the efficiency of logistics for the area of storage and picking of special materials
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Increasing the efficiency of logistics for the area of storage and picking of special materials

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Keywords: logistics, efficiency, storage, picking.
Abstract: The article deals with increasing the efficiency of logistics flows for the area of storage and picking. The aim of the processed study was to focus on the analysis of logistics activities and processes, the state of supply and inventory management. An assessment of the effectiveness of the introduced information system at the selected warehouse was carried out, which led to changes in a positive direction in the very process of storage and management of special products. The study presents the design of variants, the selection of the optimal one using selected decision-making methods and the introduction of a new warehouse system, which leads to the efficiency of the entire storage process in the NPI (New Product Introduction) warehouse. The output of the study is also the implementation of the selected variant into industrial practice, which is declared by the elaborated project of the introduction of the selected variant. The article is a contribution related to the process of implementing a warehouse and picking system for specialized material items.

1 Introduction

Supply chain logistics combines two basic processes. The first task of supply logistics is the actual supply. It combines physically executed operations and processes such as receipt and transport of goods, planning and management of warehouse operations and, last but not least, controlling the flow of information and materials within the logistics operations. The general objective of supply logistics is identical to the overall objective of logistics, namely, to reduce costs and increase the efficiency, fluidity and flexibility of logistics. The second area of supply logistics is focused on market analysis, monitoring price trends, searching for the optimal supplier as well as establishing a favourable relationship between customers and suppliers or negotiating adequate contractual terms. It can therefore be said that this part of supply logistics is directly focused on procurement. Purchasing is increasingly conditioned by the collection and analysis of information from markets, suppliers and competitors that lead to developing particular supply strategies.

Strategies represent the planning and management processes of logistics. Thus, in the market, a venture can either adopt a strategy of active positioning (an active effort to seek the best terms and agreements in the market) or it can afford a passive strategy where the market itself can offer the best terms and conditions. The choice of strategy and the market position depend on a large number of factors and on the actual goods or materials and hence on the type of market and its competition.

Logistics is a very broad field that largely affects the proper operation of the entire company. As long as all logistics activities work correctly, we hardly notice logistics. But we will realize its importance the moment any problem suddenly arises, be it during supply, storage, or shipment of goods. The effects of bad logistics can be serious for the company, in some cases even liquidating. For these and other reasons, more and more emphasis are placed on logistics in companies [1,2]. We rank warehouse management among important parts of logistics as a whole.

Logistics deals with the overall optimization, coordination and synchronization of all activities, the chains of which are necessary to economically achieve a given final result [3,4]. The logistics system as a whole consists of three subsystems:

- Material system – this includes material records, material security management, implements material flow.
- Information system – works with data on the previous, current and expected state of the material flow.
- Management system – processes information at the point of origin in real time. The effectiveness of this management is influenced by the quality of information, its availability and timeliness.

More and more demands are placed on the optimization of stock levels. In the case of optimal inventory management, costs are not the only aspect we follow. For each company, it is necessary to assess the way of

inventory management individually. Each company has different economic conditions, different inventory management and valid legislative standards of the country in which the economic activity is carried out. It is important to observe the following aspects to determine the right strategy:

- degree of processing of the item (production stocks, unfinished or finished products),
- type of demand (dependent, independent, trending, seasonal),
- the place in the company's material flow where the stock is currently located,
- types of stocks according to ABC classification (XYZ) analysis.

Warehousing is an important component of the entire logistics process of the company, and logistics managers are well aware of the need to improve the productivity of warehouse operations. This can be done in many ways. Most often, system-oriented programs are used for this purpose (they directly affect the way different elements of the logistics system interact) or programs based on motivation (employee training, rewards, bonuses) [5-7]. Optimizing warehouse processes in an economic sense is not a priority for the company, because it does not fundamentally affect the value of the product, as the storage processes produce only a few activities that add value to the product. The main reason for the emergence of various problems in the warehousing process is the fact that there is no standard in this area from which businesses can base themselves [8-10]. Therefore, if a company wants to start optimizing its warehouse processes, it must first analyze them, specifically create:

- analysis of efficiency and productivity of work in warehouses in terms of increasing and reducing costs. The most suitable solution is the automation of warehouse operations,
- performance analysis between supply and customer chains within the selection of a suitable storage system and integrate this system into the material flow.

However, many causes of excess storage can be relatively easily eliminated with the help of modern technologies or at least significantly reduce their impact on the costs and efficiency of the company's production. Increased visibility in the logistics chain can lead to greater efficiency in all processing activities. The introduction of automation into the storage process makes it possible to obtain real-time information about stocks, as well as information about the state of progress and storage locations, etc. This system allows companies to gain control over all activities in the warehouse and thus significantly increase the overall productivity of warehouse activities [11-14].

2 Methodology, case study

Each enterprise has its own specific purchasing goals, its own purchasing policy and uses different procedures for the procurement of input materials depending on the nature of the manufactured products, the size of the enterprise, the distribution of suppliers and the technical equipment of the enterprise. In the investigated company, the inventory management system is closely monitored. Inventories are created in centers directly related to production or shipping, from the material itself needed for production, through stocks of unfinished production to final products.

In general, the supply process consists of sub-activities such as purchasing or ensuring inputs into the production process, then transport to the warehouse and storage itself. All the company's activities are elaborated in detail in the company's internal directives, defining the goals, powers and responsibilities of individual employees, and specifying the exact procedure for the course of individual activities in the company.

2.1 Purchase

Ensuring materials for the smooth running of production is an essential basis for early and complete satisfaction of customer requirements. The entire shopping process in the company is ensured by the so-called material planners whose task is the purchase of incoming components, including the incoming inspection of these components. The purchase of material is carried out on the basis of a pre-approved production plan. Special components and material for special production are always ordered in exact quantities, according to customer requirements, as the price of these input materials is always higher than for mass-produced components.

2.2 Transport to individual warehouses

Ensuring the transport of input materials to the company's external warehouses is carried out by several suppliers, i.e. different external transport companies, depending on the countries from which the goods are ordered.

Within the framework of suppliers from the EU, trucks with a transport time of approx. 7 days are used as a standard for the transport of materials and components. The second option is vans, which is a faster method of transportation, but is not used as a priority. In the case of an emergency, it is possible to provide a supply to the internal warehouse within a maximum of 24 hours, if the goods are available at the supplier's warehouse.

From Asia, the transit of material is primarily carried out by ship transport, as this type of transport is the cheapest. The delivery time is approx. 8 to 10 weeks, but since production is planned well in advance, or for a longer period of time, a longer delivery time is no problem. The second option is train transport, which has a transport time of about 4 weeks and is used occasionally. Exceptionally, a special flight can also be used, which is of course a

financially expensive matter, therefore it is used only in necessary urgent cases. Transportation from the external warehouse to the internal warehouse takes place continuously, and the company uses the services of an external company for this.

2.3 Storage

Warehouse management in the company fulfills an important role as an intermediate link between production and consumption, so it is part of the logistics chain in the company. Warehousing is a set of activities including the receipt of material into the warehouse, connected with incoming inspection, storage and issue of material.

Main external warehouse: The warehouse serves for the accumulation of supplies of input material from various suppliers, the subsequent sorting and repackaging of input components. According to the production plan, the warehouse management system (MHS) evaluates the need for material and components for the next 24 hours. Based on this request, the necessary material is dispatched to the internal warehouse

External packaging warehouse: The warehouse is used for packaging material, or packaging for finished final products

Internal warehouse: It is located right next to the production hall in the main building of the company. It is used to store materials needed for planned production for the next 24 hours. At the same time, it also stores semi-finished products, but also finished products waiting to be shipped to the customer, so it also has several zones. Internal warehouse is equipped with rack systems with narrow aisles designed for storing large and medium-sized components. Small components are stored in KARDEX AND MODULA4 lean lifts. In addition to these systems, the warehouse also has drop gravity stands, so-called Kan Ban, which also contribute to the smooth and efficient use of warehouse stocks. Each type of material has a precisely determined position/shelf where it should be stored.

The MHS stock management system is also used in the internal warehouse, which continuously evaluates the need for material according to the production plan and according to the current consumption of the given material on individual production lines, performs automatic material consumption on the production lines. If necessary, the system will send a request to the internal warehouse, which type of material from which position in the warehouse and in what quantity must be moved to the production hall on a specific production line. This process is carried out continuously by several suppliers, each with specific components and specific production lines. On the return journey, warehouse workers collect empty containers and store them for a certain time in the company's internal warehouse. Other employees of the warehouse have the task of collecting full packaging boxes with finished final products from individual lines, and also store them in the internal warehouse.

The flow of packaging, materials and final products: The customer sends empty packaging to the packaging warehouse, which is checked, cleaned, weighed, prepared and then shipped to the internal warehouse in the required quantity based on the report from the production plan. There they are unloaded and subsequently delivered to individual production lines in accordance with the production plan. Full packaging boxes are concentrated in an internal warehouse, where they are checked and weighed. If necessary, e.g. when the scale does not fit, the number of pieces of components in individual boxes is recalculated. Boxes that are in good order proceed to the next process, they are either stored for a certain time or, in the case of urgent orders, they go directly to export for the customer. From there, the empty packaging is returned to the external packaging warehouse.

NPI department in the company: NPI is a department that, based on specific requirements from customers, is responsible for introducing new products into NPI/New Product Introduction production. In this department, the responsible employees deal with both the technological assessment of the production process and the quality of these new products, as well as the material flow of components that do not yet fall into the phase of serial production, and thus must be specially marked and their application in production must be separately registered and ensured. Project leaders are responsible for all ongoing projects in this department, who are responsible for the entire course of individual projects. Project processes are managed by process project engineers who are in charge of specifications, installations, but also deal with all design elements of manufactured products. Project coordinators are in charge of all logistical flows within individual ongoing processes (Figure 1), whether they are ordered components needed for special production or already manufactured products. The NPI department also has its own experts to assess the quality of manufactured special products.

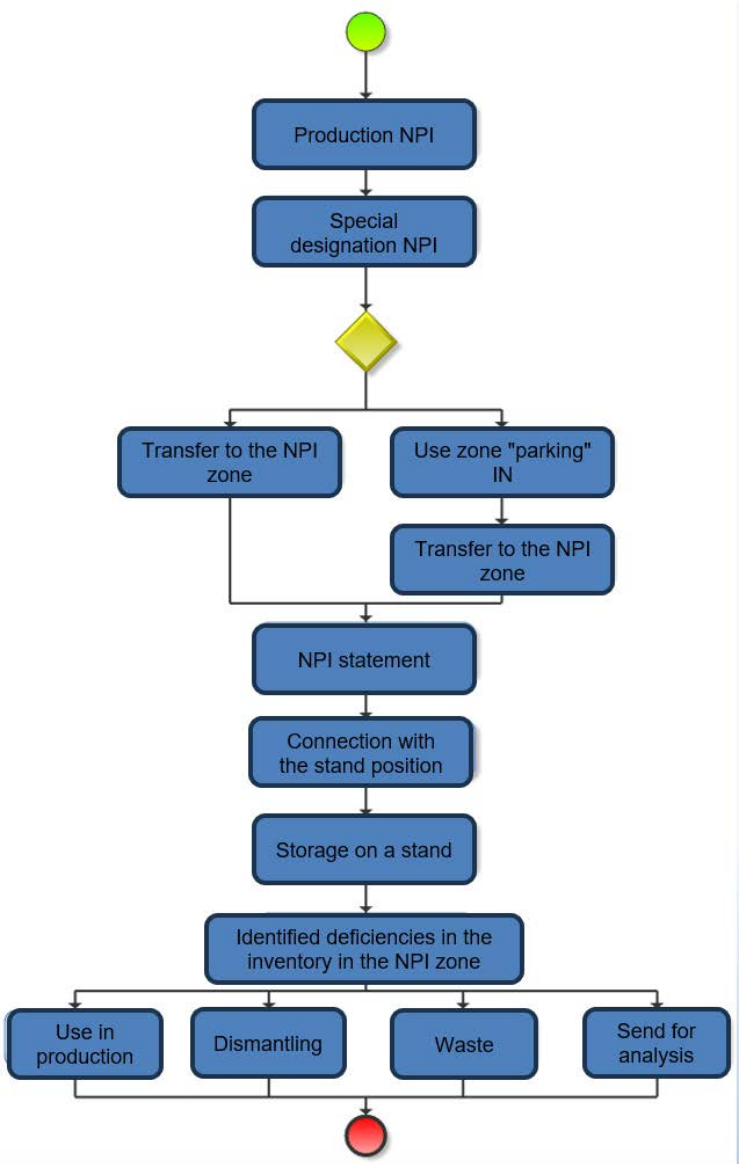

Figure 1 Flow diagram of the storage process in the NPI warehouse

2.4 Identification and description of the main identified problems

The main identified problems:

- Manual writing of identification labels

We consider the biggest shortcoming in the NPI warehouse to be the fact that the labels containing the data on the manufactured SBR products are written by hand by the employees. With this manual form of writing out identification labels, various errors may occur during the receipt, storage and issuance of NPI material, which the worker may not notice. Inaccurate material identification based on inaccurate or erroneous data on the label, inaccurate allocation, result in error rates.

- Incorrect and incomplete data on identification tags

It happens that the material remains only on the transport cart or is stored on the shelf without being entered into the MHS database. This happens when the identification label is not written completely, it lacks essential input data, e.g. the number of the technician who produced the given SBR batch. Thus, the material cannot be thoroughly identified, and this later causes various problems.

- Insufficient identification system of SBR products

The lack of an automatic NPI identification system is felt by the department mainly during inventories. Deficiencies caused by out-of-date product data are regularly manifested, where the actual status does not correspond to the status in the company's MHS system. There is an inability to identify and locate components.

Many shortcomings are caused by the human factor. Since the SBR number is written manually and is not in the MHS system, a physical check directly in the warehouse is necessary to solve any problem.

- Lengthy and inefficient inventory

In the warehouse, there are regularly products that, for various reasons, were not properly stored and identified, that is, they are not in the company's MHS system. The inventory takes an average of 4 days, so it is lengthy and inefficient at the same time.

- Insufficient capacity of the NPI warehouse

After conducting an analysis of the current situation in the NPI warehouse, it was found that the storage of materials and stock of special products in the NPI warehouse was inefficient, limited by the capacity of the warehouse space, and also due to the accumulation of hard-to-identify items, there is less and less room left in the warehouse for handling them. Material also accumulates in the parking IN zone. Thus, work becomes increasingly inefficient and the possibility of error increases.

- Unsecured "parking" zone

It can be accessed by every production operator, but also by all other employees who have the competence to get into the production hall. It is not possible to check it in any way, so it sometimes inadvertently happens that special SBR products are used from it for mass production and thus become devalued

- Presence of excess stock

While performing the analysis/inventory in the NPI warehouse, we found that a significant number of products and stocks could not be identified, we could not prove their need for future planned SBR production, or they were already after the date of planned production or shipment to the applicant of this special production batch.

- Redundant movements of workers

When dealing with various situations and problems that occur on a daily basis, it is necessary for an employee of the NPI department to physically check SBR products directly in the warehouse.

2.5 Proposal of a solution for streamlining inventory management and implementation of the selected variant

Implementation of the Kardex Shuttle storage system

The new system designed by KARDEX consists of 1 Kardex SHUTTE vertical elevator module with a single access opening for the dispatch area. The new solution requires only 13.5 m² of space to store more items than in the original warehouse. The vertical elevator module would be located directly next to the production hall like the original premises of the NPI warehouse (see Figure 2), but it would occupy much less space.

The introduction of this option would not require any intervention in the building or other construction work. The only modifications would be related to adapting the electrification and freeing up space for the new storage module.

As part of this solution, we could increase the capacity of the NPI warehouse by up to 38%. One of the biggest advantages of this variant of the solution is the possibility of streamlining the storage process in the NPI warehouse with new warehouse software.

Advantages:

- saving space in the production hall,
- increasing the capacity of the NPI warehouse,
- improvement of the storage process with new software,
- improved ergonomics when handling goods.

Disadvantages:

- the necessity of training employees,
- the need to prepare a place for the new system.

The Kardex Shuttle is the most efficient way to keep parts safe, clean and organized in a very small and compact space. It allows loading up to 480 kg on one shelf. The installed KARDEX module includes 34 such shelves, Figure 3.

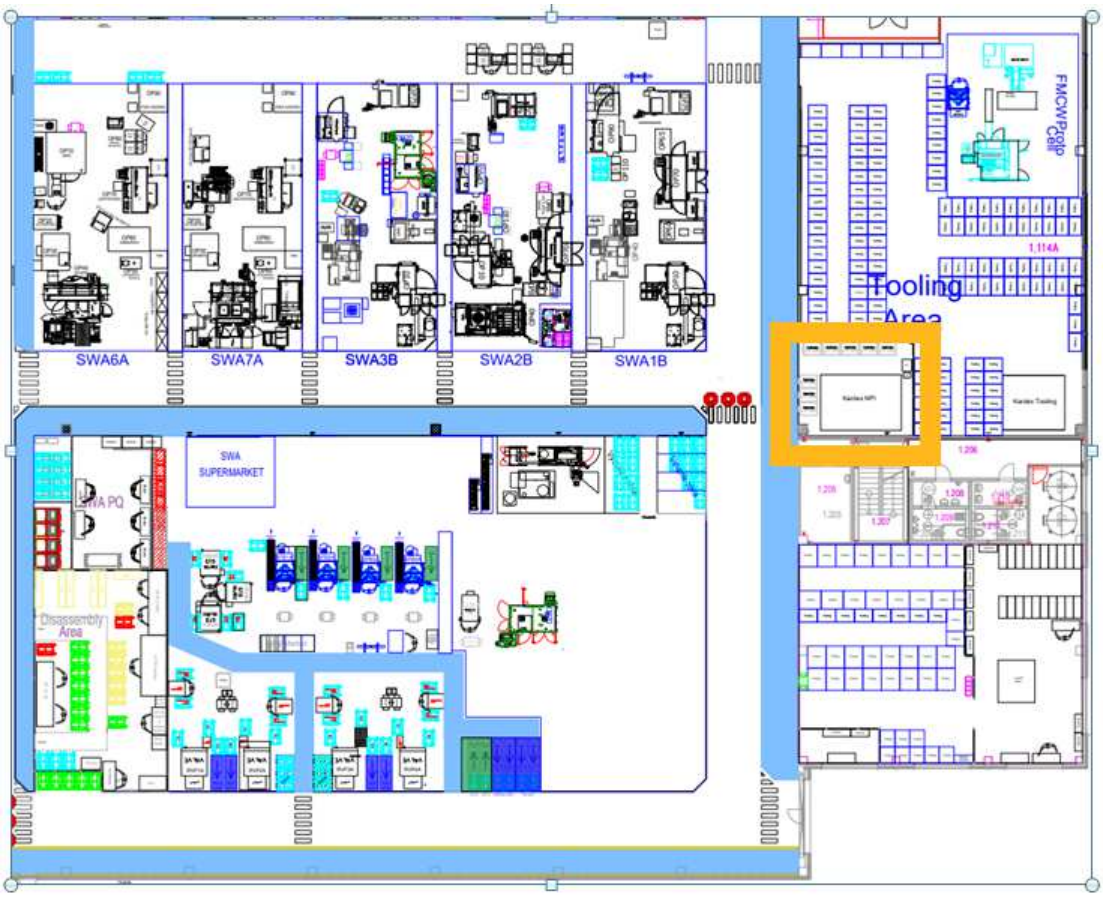

Figure 2 Layout of the production hall with markings of the proposed KARDEX module

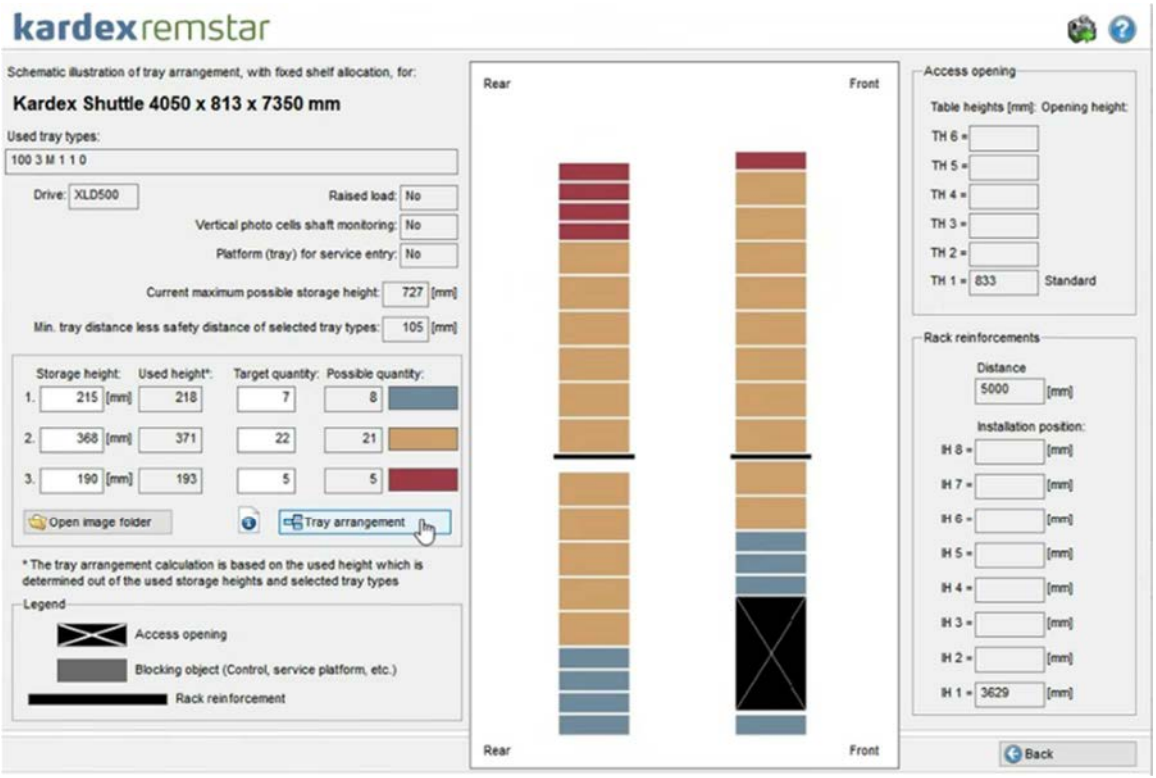

Figure 3 The final arrangement of the shelves in the KARDEX system

2.6 Design of a new form of identification labels

When designing the new form of identification labels, all identified deficiencies on the original labels were taken into account, while the practical experience of the employees of the company's NPI department was also based on it. The design of the new label can be found in Table 1.

	SBR / 8497 PLANT	1070008695874	
SBR NUMBER	Test	LINE	TEST
PART NUMBER	999999-9999	PID	117161
CREATE MATERIAL:		DATE	12/14/2022 6:15:26 PM
QUANTITY	100	BOX TYPE	3 GOLDEN

Table 1 The new form of the identification label

The most important change in the new storage system, and for streamlining the functioning of the NPI warehouse, is that it contains the SBR code of the material (Figure 4), which could not be entered into the MHS system. The new Power Pick information system offers this option. The SBR code is located on the new identification tag and can be read directly with a scanner.

Materiál	Aktu Σ	SBR	ID Kontajner	Pořadové č Σ	Bin	datum naskladně
		fh				
847321-0007	4	FH35	1070008651008	4	2 CHRA	06.12.2022
904105-0009	17	FH47	1070008770138	14	1 SWA	12.01.2023
904105-0009	32	FH47	1070008770134	14	1 SWA	12.01.2023

Figure 4 The items in the new Power Pick storage system

The main benefit of the introduction of the new storage system is the streamlining of the inventory process in the NPI warehouse, but also of all other processes related to the SBR procedure at the NPI department in the company. The purpose of the introduced system is, among other things, to simplify the supply of NPI products on the production lines and more clearly record the stock of these products.

2.7 Stock software Power Pick

Above all, the inventory management solution must be simple with a clearly structured process and minimize the risk of errors in all tasks. Power Pick Global warehouse management software from KARDEX s. r. about. meets these requirements, increases accuracy, efficiency, safety and flexibility, optimizes storage in combination with KARDEX machines, Figure 5.

The system provides simple storage and collection of goods, warehouse management, spatial management, reporting and simple management of user rights. More than 25 additional options include advanced reporting, batching, kiosk storage, label printing, SAP integration, serial number handling, weight management and zone handling. Thanks to the new storage system in the NPI warehouse, we managed to achieve the following benefits.

- elimination of excess stock,
- reduction of redundant movements and work,
- more efficient and faster inventory execution,
- streamlining the storage process by scanning,
- streamlining the storage process by scanning,
- increasing the storage capacity of the NPI warehouse,
- saving floor space,
- improvement of workplace ergonomics.

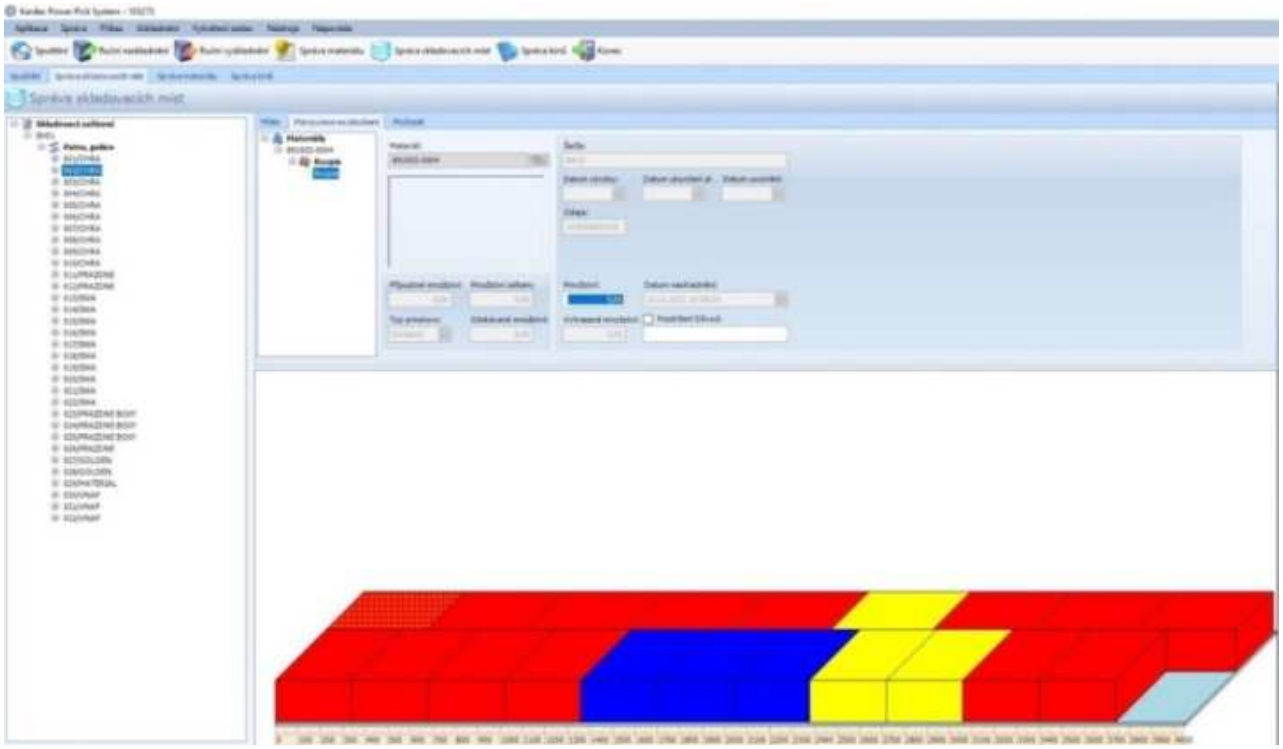

Figure 5 The arrangement of CHRA boxes in the KARDEX system

Evaluation of benefits

- streamlining the storage process by scanning,
- more efficient and faster inventory execution,
- increasing the storage capacity of the NPI warehouse,
- improvement of control management in the NPI warehouse,
- elimination of excess stock,
- reduction of movements and work,
- saving floor space,
- improvement of work ergonomics.

Financial benefits are processed in Table 2.

Table 2 Financial benefits from the implementation of new system

	Floor area in m^2	Price per m^2/month	Price per month	Number of months	Price per year
Before	186	4,5 €	837,- €	12	10 044 €
After	32	4,5 €	144,- €	12	1 728 €
Difference	**154**		**693,- €**		**8 315 €**

3 Conclusions

The analysis of the processes resulted in specific outputs with the definition and evaluation of the shortcomings of the warehouse system implemented in the company, and possible variants of solutions to the identified problems were proposed, which will contribute to increasing the efficiency and effectiveness of storage through introduction WMS. The main mission of the WMS system is to manage and visualize data flowing from the warehouse in real time.

The system works as a stand-alone application, i.e. software with complete or partial configuration options. The information received on operations, or the flow of material, equipment or people is provided by technologies such as AIDS, RFID and RTLS. Such software and hardware system implementations offer:

- increased control over warehouse operations,
- control over the flow of materials, equipment and manpower,
- increased work efficiency,
- increased storage capacity,
- reduction in operating costs,
- reduction of failure rates in material operations such as dispensing and receiving,
- increased organizational efficiency in storage.

The implementation of WMS is initially costly in both time and money. Metrics have been introduced to make

decisions about investing in a WMS system that are directly tied to the business strategies and financial capabilities of the enterprise. The metrics include three main categories, namely:

1. order fulfilment,
2. stock management,
3. productivity.

Setting such conditions serves as a justification for investment and constitutes the first step in
building a WMS. Placing the right emphasis on specific requirements helps in optimising the
potential design of both the system and the technologies deployed in the space.

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Optimizing the order picking and delivery process to the final recipient

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Abstract: The aim of this study is to analyse and evaluate the order picking process and the transport of products to customers, taking into account the specific characteristics and potential of small and medium-sized industrial enterprises. Scientific standards and selected indicators for measuring the efficiency and quality of transport and order picking processes were used to achieve the intended objectives. The research was conducted in a small, family-owned manufacturing and trading company specialising in the production and sale of wrought iron finishing elements and fences. The analysis covered both internal and external transport processes. It was shown that the order picking process in the studied company is largely based on manual procedures, which, despite high precision, generates time-consuming activities related to the movement of warehouse employees. External transport efficiency indicators showed high efficiency and appropriate use of transport resources. The high quality of deliveries, as measured by on-time and reliability indicators, confirms customer satisfaction. The study was conducted in one company, which is a limitation. Future studies should include more companies from the same sector. Proposed improvements need to be verified sometime after implementation and solutions resulting from data analysis can help SMEs in similar industries to improve their logistics processes. The work brings a new approach to the analysis of order picking and transport processes in the context of SMEs, providing practical solutions and indicating areas for further research. It is aimed at logistics managers, researchers and practitioners interested in optimising logistics processes in the industrial sector.

1 Introduction

In an era of fierce competition, the activities of business entities are not only limited to production, delivering products to the target market, but also to achieving the desired sales volume, maintaining proper relations with suppliers and customers [1]. Close cooperation with suppliers and with the distributor is required. Both procurement and distribution are closely linked to the transport of materials, raw materials or finished goods. Without properly functioning transport, it is not possible to run any business. The organisation of the transport process has a significant impact on the logistics process, the fluidity of the logistics chains. Whether in warehouse management, production or finished goods transport, transport plays an overriding role.

One of the basic processes in the finished goods warehouse is order-picking, which involves taking specific types and quantities of products from the storage areas and combining them into one separate unit [2,3]. This will then be transferred to the release area for transport to the customer.

The following movements are carried out in the finished goods warehouse [4,5]:

- Receipt of finished goods from production.
- Unloading of the products: transfer to the storage area.
- Configuration of the corresponding sets of products, according to the order (picking).
- Releasing the goods, i.e. loading the products onto the means of transport.

Finished products arriving from the production line are labelled with the product symbol, name and, in the case of an individual order, its number and customer data. Such labelling facilitates the storage and, above all, the release of specific products for picking. In theory, the following types of picking are distinguished, i.e. the preparation of finished products for dispatch, according to the according to the order [6]:

- Simple picking: one person carries out a single order.
- Combined picking: combining individual orders into picking lists.
- Zone picking: picking of an order from a particular zone by one worker.

The analysis undertaken of the process of order picking and transport to the final customer, concerns a manufacturing and trading plant belonging to a small, family-owned enterprise located in Poland, in the Silesian province, in the city of Częstochowa. The company was founded in the interwar period and operated as a blacksmith shop. In 1992 it was transformed into a company, and the company is currently managed by one owner. The company is involved in the production and sale of wrought iron home finishing elements and complete

wrought iron fences, including the installation of automation. The company's development is evidenced, among other things, by a systematic increase in the range of products directed and tailored to the needs of the individual customer. An example of customer-oriented production is, for example, the realization of individual orders for armor and knightly weapons. The production and fulfillment of such orders is niche in Poland.

In the selected company, straight picking is used, which means that one warehouseman picks the goods for dispatch according to the order. In addition, a 'man to product' picking system is used [7]. This system is based on the fact that it is a man who reaches the storage area for a particular product, picks it and moves it to the picking area [8].

The results of the authors' research show that there is a lack, especially in Poland, of effective tools describing the order picking process with concrete examples. In addition, there is a shortage of commercialization of practical solutions to support the management of this process in order to optimize the activities of companies in the same industry. Most often, these topics are discussed in a general way in the context of logistics processes [9,10] i.e.: picking process optimization [11], picking automation [12-14] or inventory management in the context of picking [15,16]. Also analysed are examples of the implementation of innovative solutions in the handling infrastructure improving the discussed process [17], IT systems supporting picking processes [18,19] or working conditions in goods picking processes.

Therefore, the motives for taking up this topic were:

- The relatively small number of studies on the Polish and foreign publishing market concerning the order picking process in manufacturing companies in the forged fencing sector.
- The lack of a set of practical solutions in the context of order picking.
- The lack of scientific and research publications analysing order picking on specific examples.

The purpose of this study is to analyse and evaluate the process of order picking and transportation to the destination, taking into account the requirements and potential of small and medium-sized industrial enterprises. The authors' analysis identifies a gap in research on order picking processes, particularly in the SME manufacturing sector. It highlights the need for practical solutions and commercialization of tools to support the management and optimization of order picking, especially in an industry such as wrought iron fencing.

The research results presented will contribute to the development of a remediation plan to improve order picking and external transportation processes. Practical solutions from the data analysis can help SMEs in similar industries improve their logistics processes and overall efficiency. This opens the way for further research in order picking optimization, transportation logistics and supply chain management, especially in the context of SMEs. This highlights the importance of addressing specific industry challenges and implementing innovative solutions to drive business growth and competitiveness.

2 Methodology

2.1 Research background - the company's transport infrastructure

The transportation infrastructure of a plant is closely related to its characteristics and activities. First of all, as mentioned in the introduction, it is a production and commercial activity. The plant carries out external and internal transportation tasks. External transport is carried out to a small extent, only for its own needs. The entrepreneur owns two delivery trucks. These are Opel and Renault tarpaulin vans with a capacity of up to 3.5 tons. If necessary, the tarpaulins are pulled down. One of the vehicles is a 2018 version of the Opel MOVANO. It is characterised by relatively low fuel consumption. It can accommodate 8 to 10 pallets. The other vehicle is a 2014 Renault Master 2.3 dCi, which can also accommodate up to 10 pallets. Both vehicles are leased. The vehicles are mainly used for supplying the plant. Materials are delivered, semi-finished products intended for the production of products. Transportation is carried out over short distances. All materials are purchased from suppliers in Silesia, Malopolska, or Swietokrzyskie provinces. First of all, steel, stainless steel and, in insignificant quantities, aluminum, paints are delivered.

The plant cooperates with wholesalers based in Częstochowa. The short distance between suppliers of steel products contributes to the low transportation costs for supplies. The number of deliveries per month is variable and depends on the volume of orders. The vehicles also handle product deliveries to customers. In the case of a large order, customers carry out the pickup with their own transport. Such a decision by the plant owner is due to economic reasons. Recipients of the products are not only small locksmith stores, but also large chains of construction stores, which receive large quantities of products of varying dimensions (spans, or handles). The organisation of external transportation above 3.5 tons is the responsibility of the recipient. The owner would have to rent the means of transport (a set of tractor and semi-trailer), which would involve significant costs.

Intra-plant transport refers to the short-distance transportation of raw materials for production, inter-station transport and to the finished goods warehouse. Its task is to synchronize the flow of goods in the production cycle. The organisation of internal transportation within the plant is adapted to the specifics of production. It makes the flow of goods take place safely and at low cost. Transport of materials or finished goods is carried out along the shortest routes, using forklifts. The plant is equipped with five forklifts. Due to the parameters, the plant has purchased Still brand forklifts, which can carry loads of up to 8 tons:

- Model RX 50, which is particularly suitable for unloading and loading cars and transporting pallets in the warehouse, delivering components to workstations, makes it possible to transport loads of up to 1.6 tons in narrow spaces between workstations (2 units).
- Model RX 60 makes it possible to transport heavy loads of up to 8 tons, is used for loading and unloading of trucks (1 piece).
- Horizontal compliment cart model OPX 20/25, with a lifting capacity of up to 2,500 kg.
- Horizontal stacking cart OPX D 20, characterized by minimal twist, load capacity up to 2 tons.

They are used already at the time of receipt of loads into the raw materials warehouse. Unloading of vehicles is carried out using forklifts. These are electric forklifts, which do not emit exhaust fumes into the environment. Batteries are fully sufficient for eight hours of single-shift operation. Delivered goods are transported by forklifts to the designated location in the raw materials warehouse. All raw materials are stored on pallets for quick movement. In addition, two HPS hand forklifts are used at the plant.

Due to the nature and variety of production, transportation is carried out from the warehouse to individual stations. There are distinguished positions for the production of balustrades, railings, gates, in addition to the production of details (decorative knobs, letters, numbers, etc.), handles, hinges, building management systems, paint shop. This organisation of workstations is due to the diversity of production technologies. Internal transport is shuttle, which means that a forklift delivers a particular material to a particular workstation. On the way back, it picks up waste.

Pallet trucks are mainly used for shifting pallets with an insignificant load All forklifts and pallet trucks have the necessary technical documentation, which allows them to be serviced. Due to the plant's single-shift operation, batteries are recharged after eight hours of use.

The use of forklifts is higher in the situation of transporting raw materials to the warehouse, as well as during car loading. On the other hand, the use of forklifts in production depends on the type of orders being processed. It should be mentioned that the plant has no overhaul downtime during the year. Production takes place cyclically in one shift. Hence servicing, technical inspections of forklifts take place successively, so that the plant is not deprived of means of internal transport.

Thanks to the delegation of authority, each person operating a particular forklift is responsible for its proper use, controlling its technical condition, as well as its daily operation. He or she is responsible for entries in the equipment records of maintenance performed, fluid changes, tires, etc. Delegation of authority also promotes the economical use of means of transportation. The correct organisation of internal transportation promotes the proper course of the production process. This is because the products are delivered at the right time to a specific position. There are then no unforeseen interruptions.

Another type of transport is small overhead cranes, which allow the transportation of large elements, such as railings, balustrades, gates, fence spans for powder coating. Painting is preceded by cleaning the welded elements from impurities. The plant has an automated washing station, where metal parts are cleaned of grease and protected against corrosion. Paint (powder) is applied to the thus prepared surface in a spraying manner.

Depending on the order, the elements are painted in different colors. The parts are then sent to an electric paint oven, where the paint is cured. The painted parts are heat-treated for about 20 minutes at a temperature of about 200° C. The paint coating makes the metal parts resistant to moisture, temperature changes, UV rays, chemicals, and, above all, to corrosion and mechanical damage. These properties are important for products that are used in natural environments. Painted components are subject to detailed inspection and then transported to finished goods warehouses. When discussing internal transportation issues, it is also necessary to characterize roads, storage, unloading and loading points for raw materials/products. The maneuvering area provides a safe approach of vehicles to the unloading or loading ramp. Intra-plant roads are of adequate width to ensure maneuvering of vehicles. The main roads are 1.5 to 2.0 meters wide. However, between stations up to one meter. Larger distances are between individual departments, i.e. the warehouse, the production section, the paint shop and the finished goods warehouse. These distances take into account health and safety rules, including fire safety. It should be noted that the roads are smooth, without thresholds, marked in yellow. The speed of internal transportation means must not exceed 5 km/h. Employees use the internal parking lot, the location of which does not impede the entry and exit of external transport vehicles. The length of the ramp and door openings ensure the free reception and transfer of loads. Lift gates are used - segmented.

2.2 Research methods and material

The aim of this study is to analyse and evaluate the process of order picking and transportation to the destination, taking into account the requirements and potential of small and medium-sized industrial enterprises. This main objective required answering the following research questions:

1. What is the organisation of internal and external transport in the company in question?
2. How is the picking process carried out in the company?
3. How is the transport of finished goods to customers organised?

In order to obtain answers to the questions posed, a case study was selected as the research method. The research

tools used were - a direct casual interview with the owner of the company and a critical analysis of documents provided by the company under study. The interview was conducted in July 2022. The analysis of procurement documents covered the entire year 2022.

Selected indicators were used to measure the efficiency and quality of transportation and picking. The data obtained allowed the calculation of external transportation costs on a monthly and annual basis. The originality of the presented material lies in the development of a recovery plan for the picking process. The collection correctness index was calculated to measure the correctness of product picking. A measure of the correctness of the completion of products is complaints of non-conformity with the customers' order, i.e. the collection correctness index. For this purpose, the following formula (1) was used:

$$ICC = \frac{N}{T} \quad (1)$$

ICC - Correct collection,
N - Number of improved orders completed,
T - Total orders completed.

The indicator value for the six warehousemen involved in picking and shipping products for 2022 is presented. The efficiency of the process of transporting goods to the recipient was also diagnosed. For this purpose, selected indicators were used, i.e:

- Vehicle utilisation rate - k_p.
- Technical readiness index of rolling stock - k_g.
- Vehicle time utilisation rate - k_{hp}.
- Utilisation rate of technically fit vehicle - k_{up}.
- Vehicle load space utilisation rate - w_{vp}.

3 Results

Simple picking is used in the company, which means that one warehouseman picks the goods for dispatch according to the order. In addition, a 'man to product' picking system is used [20]. This system consists of a man reaching the storage area for a specific product, picking it and moving it to the picking area [21-23]. Warehousemen begin the picking process when they receive the preparation of goods for shipment. This order includes:

- An inventory of the products, including their characteristics.
- Number of pieces (packages).
- The location of the products.

In cases of small orders, picking of goods is done manually. The warehouseman delivers the products according to the order to the picking point. As mentioned, he carries out only one order. The process of picking a single, specific product consists of the following steps:

- Scanning the storage location code.
- Scanning the code from the label of a particular product.
- Picking up the particular product and transporting (transferring) it to the picking location.

A warehouse is a place from which finished products are manually retrieved by a designated warehouseman. Such a solution requires the allocation of adequate time not only for finding and retrieving the product, but also for the movement of the warehouseman. The order picking process is often time-consuming. Figure 1 shows the percentage of individual operations that constitute the picking process.

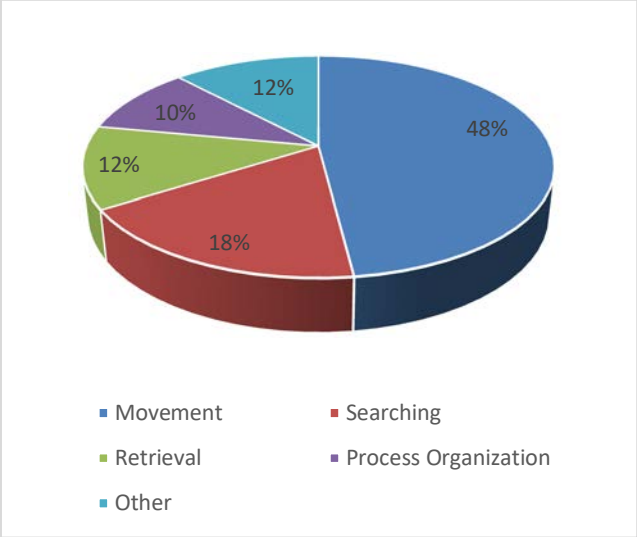

Figure 1 Picking process - % share of individual activities

Analysing the data presented in Figure 1, it should be noted that almost half of the time involved in picking an order is the movement of the warehouse worker. This person does not always use forklifts. In the case of orders for details such as handles, hinges or other small items, the warehouse worker moves between the racks on foot. Despite the use of automated warehouse handling (RFID), the retrieval period for product data is still relatively long. The time taken to retrieve products varies, depending on the level of storage and also the location (shed). It is clear that the fastest picking time is on the first level and the longest on the highest level. It should be noted that the total time it takes to pick five products and transport them to the picking area is 4 minutes. It should be noted that the average speed of the warehouseman is 5 km/h. His route is optimal. Similar picking times occur when using forklifts when the products are large and heavy. The picked goods are moved/transported to the picking area. There, the warehouseman assembles the goods. The organisation of picking takes place according to the order of shipment, order by order. Small-sized goods that are on the order list are stored on pallets and then protected with foil or packed in cardboard boxes. Once all items have been completed,

the prepared goods are handed over for dispatch to the customer. Associated with picking is the quality of shipment preparation. The correctness of the completion of the products is measured by complaints of non-conformity with the customers' order, i.e. the collection correctness index.

The Table 1 below shows the value of the indicator for the six warehousemen involved in picking and shipping products for 2022.

Table 1 Collection validity index

No. of warehousemen	Number of correctly completed orders	Completed orders	Collection accuracy rate
1.	8,370	8,680	96.4%
2.	7,750	8,060	96.1%
3.	5,580	5,890	94.7%
4.	8,624	8,932	96.6%
5.	7,320	7,625	96.0%
6.	7,540	7,830	96.3%

Considering the values of the indicators presented, it should be noted that they are close, at just over 96%. Only in one case, that of the warehouseman processing the smallest number of orders, is this indicator below 95%. At the plant, each poorly executed order is analysed for products that were mistakenly completed. The most common mistakes involve details, metalwork, handles. These products are produced in different assortments, colors, which can result in incorrect classification of the product to the order. Analysing the mistakes made, it was found that they are mainly due to lack of attention, absentmindedness of warehouse employees. They mainly concern:

- Taking the wrong number of products (inconsistency with the order).
- Taking products from the wrong place.
- Wrong storage.

It should be mentioned that the plant accepts such complaints and sends the correct product at its own expense. Also, rechecking the order before sending the completed cargo eliminates mistakes. Efforts should be made to improve order picking, through more effective use of IT systems. Correct labelling of products, proper storage will help to reduce the number of complaints. Incorrectly completed orders incur costs due to complaints and corrections. In the plant, each wrongly completed order is analysed for products that were mistakenly completed. The picking process is completed when the transport unit is handed over to the dispatch area.

The company in question does not organise external transport if the load exceeds 3.5 tonnes. Transport of larger goods is carried out (organised) by the ordering party itself. As mentioned, the main customers for the products are locksmith shops, wholesalers, chain shops or individual customers. External transport is carried out exclusively within the country, primarily in the Silesian, Opole and Lesser Poland Voivodeships. Thus, transport is carried out over short distances. The task of the driver receiving a transport order is to work out the shortest possible route. This task is facilitated by the GPS system.

One vehicle covers an average route of 300 km in one day. There is rarely a further trip of more than 500 km per month. The cost of transport is:

- Fuel consumption 9 litres/100 km, i.e. about 30 litres per day x 5.5 PLN per litre: about 165 PLN (monthly 3,630 PLN, for two cars about 7,300 PLN).
- Driver's remuneration including other benefits: PLN 6,500 (two drivers PLN 13,000 per month).

The monthly cost of fuel and work of two drivers is PLN 20,300. When calculating the cost of transport, we will also add:

- Insurance including AC: PLN 2,500.
- Depreciation approximately: PLN 2,000 per year.
- Servicing: approximately: PLN 3,000.
- Tyre replacement: PLN 3,200 per year.
- Other expenses, e.g. vehicle washing: PLN 3,000.

On the basis of the data presented, it should be concluded that the annual cost of external transport is PLN 257,300. Most funds are allocated to driver remuneration and fuel. In the case of delivery of products to the recipient, the cost of transport is mentioned in the product sales contract. Drivers making deliveries on the return journey collect raw materials from suppliers, which eliminates empty runs. Managers also analyse the efficiency of external transport using selected metrics. These metrics are shown in Table 2.

Table 2 External transport performance indicators for 2022

Meter	Formula	Indicator value
Vehicle utilisation rate - k_p	$k_p = \frac{T_v}{T_c}$ T_v – lifetime of the vehicle T_c – total inventory time	83%
Technical readiness index of rolling stock - k_g	$k_g = \frac{T_u}{T_u + T_o}$ T_u – time of use of means of transport T_o – vehicle operating time, i.e. inspections and repairs	94%
Vehicle time utilisation rate - k_{hp}	$k_{hp} = \frac{T_j}{T_p}$ T_j – driving time of the vehicle T_p – total working time	84%
Utilisation rate of technically fit vehicle – k_{up}	$k_{up} = \frac{T_p}{T_u}$ T_p – total working time T_u – time of use of means of transport	94%
Vehicle load space utilisation rate - w_{vp}	$w_{vp} = \frac{v_l}{V_p}$ v_l – volume of cargo to be transported V_p – the volume of the loading space of the means of transport	81%

Considering the presented values of the indicators, it should be concluded that their values are appropriate. The value of the vehicle utilisation rate - 83% - indicates a significant use of vehicles for transporting products and importing raw materials. Drivers are almost fully utilised for transport tasks. The technical readiness index also takes on a high value - 94%. The cars are relatively new, which translates into their low failure rate. Linked to the vehicle utilisation rate is the driver time utilisation rate. The calculated indicator has a value of 84%. The drivers' total working time consists not only of transport, but also of loading and unloading. The good technical condition of the vehicles is evidenced by the high value of the technically efficient vehicle utilisation rate - 94%.

The lowest value was recorded in measuring the use of the cars' cargo space. Cars can hold up to 10 pallets of cargo, but the order is not always that large. Managers prefer to deliver cargo to a customer faster, rather than wait for an order from another customer with a similar direction of transport. In the case of an increased number of cargoes waiting to be transported, they are consolidated onto a single mode of transport. Based on the indicators presented, it should be concluded that the efficiency of transportation is significant. The means of external transportation are properly used. Another group of measures of external transportation concerns its quality. Table 3 shows the values of selected transport quality measures.

Analysing the quality indicators of external transportation, it should be noted that they are very high and therefore satisfactory. The level of the delivery quality factor - 97% indicates that only 3% of deliveries were not accepted by customers. Reliability of deliveries is at 94%, which means that 6% were complained about by customers In this case, it is not about compliance with the order, but about possible damage to the cargo during transportation. Due to the short distances between the manufacturer and customers, the on-time delivery rate is very high - 98%. Delays in deliveries may be due to road congestion caused by the construction of the Częstochowa bypass and the connection to the A 1 in Dźbów (Silesia Province, Poland).

Table 3 External transportation quality indicators for 2022

Measure	Formula	Value of the indicator
Quality of delivery	Delivery volume accepted by customers//total delivery volume	97%
Reliability of delivery	Number of advertised deliveries/number of total deliveries	94%
Timeliness of delivery	Level of deliveries within the agreed timeframe	98%

Based on the data presented, it should be noted that the production and trading plant constantly analyses the efficiency of transportation, its use and the quality of deliveries. Despite the modest fleet, the task of delivering products to customers is carried out on a regular basis. Two delivery trucks fully meet the needs in terms of product deliveries, as well as transporting finished products to customers. A great convenience in the field of transportation is the fact that a significant part of the production is received by its own transport by locksmith stores or wholesalers, construction stores. Such a solution of transport needs affects savings in terms of costs incurred.

Drivers, perfectly familiar with the routes safely deliver goods to the indicated address. Each trip is made in accordance with the order. It is the responsibility of the drivers to properly secure the cargo, unload and control the quantity and type of transferred products in accordance with the shipping documentation.

4 Discussion

The challenges faced by SMEs in the manufacturing sector primarily revolve around common difficulties in effectively managing costs and processes, particularly in areas related to order fulfillment and transportation. Effective management of production processes, order fulfillment, and transportation requires continuous analysis and improvement, which can be challenging for SMEs due to limited resources and capabilities. Implementing strategies such as reusing packaging, employee engagement, and adherence to transportation regulations is crucial in the context of production. Leveraging modern technologies such as route optimization and vehicle tracking can improve delivery efficiency. Continuous improvement of logistic processes is essential for the competitiveness of SMEs in the manufacturing sector.

The diagnosed company, which operates in the area of picking and transportation, faces the challenge of effective cost management and process optimization. One of the key aspects of cost reduction is the reuse of bulk packaging, sourced from home improvement store chains and wholesalers. The quality of picking, a key component of the supply chain, is closely dependent on the human factor. Inattention or absentmindedness on the part of employees can lead to errors and longer lead times. Employee involvement and motivation have a significant impact on the work atmosphere and the results achieved. The value of the company is conscious employees who realize the benefits of following procedures, including health and safety rules. Another area for improvement is external transportation, where cost analysis and possible outsourcing can bring savings. Developing regulations for the application of transportation rates, taking into account various factors such as distance, loading and unloading activities, is a key step in managing this area. When it comes to loading transportation equipment, it is important for warehousemen and drivers to work together to secure cargo safely and properly. Also, efficient management of shipping documentation, especially in the era of electronic information exchange, is essential for the smooth operation of the process.

The efficiency of deliveries can be increased with the use of GPS, which allows optimization of routes, analysis of fuel burn and real-time location of vehicles. It is also worth focusing attention on the after-sales stage, where customer complaints should be properly analysed and addressed.

The lack of research on customer relations is an area for further development. Conducting customer surveys, evaluating, among other things, meeting order deadlines, the condition of goods after transport or speed of delivery, will allow a better understanding of customer needs and improve the quality of service.

Despite the competitiveness of the market, the plant's strength is in delivering products in line with customers' needs. Modern tools, such as visualization of fencing elements on the website and social media presence, can expand the market. Offering additional services, such as gate automation and video cameras, adds to the company's strengths. In the pursuit of complete customer satisfaction, it is important to continuously improve processes and analyse results at both the completion and customer service stages.

Continuous process improvement and adaptation to changing market conditions are crucial for the success of small and medium-sized manufacturing enterprises in today's competitive business environment.

5 Conclusions

The study focused on the processes of order picking and transportation in the context of small and medium-sized industrial enterprises. It was demonstrated that the order picking process, particularly in the examined production and trading plant, largely relies on manual procedures. Despite the manual nature of picking, the accuracy rate consistently indicated a high level of precision, averaging over 96% for the involved warehouse employees. The study identified efficient order picking processes; however, it also highlighted challenges, such as time-consuming activities mainly related to the movement of warehouse personnel within the facility. Despite the use of automated warehouse handling systems, the picking time significantly deteriorated, especially for small items. In addition to the mentioned improvements, when considering the picking sphere, it is essential to focus on:

- Shortening the picking process time, which is synonymous with increasing the productivity of the finished goods warehouse.
- Minimizing errors occurring at the preparatory stage.
- Reducing picking-related costs.

Reducing the number of errors will contribute to reducing the number of customer complaints, thereby increasing satisfaction with the plant's cooperation and products. The conducted analysis particularly favours the elimination of downtime, duplication of actions, or wastage.

The transport infrastructure of the examined plant primarily focuses on short-distance external transportation, mainly within the Silesian, Opole, and Lesser Poland voivodeships. The plant uses two delivery vehicles, which efficiently cover an average of 300 km of route per day. The use of GPS systems helps optimize routes, ensuring timely deliveries to customers. The efficiency of external transportation was assessed using various indicators,

including vehicle utilization rate, fleet technical readiness index, vehicle utilization time index, technically efficient vehicle utilization rate, and vehicle cargo space utilization rate. These indicators consistently indicated a high level of efficiency and proper utilization of transportation resources. The study also evaluated the quality of deliveries using indicators such as delivery quality, delivery reliability, and delivery timeliness. The results showed a high level of customer satisfaction, with a delivery acceptance rate of 97%, reliability at 94%, and timeliness at 98%. Despite the overall efficiency and quality of order picking and transportation processes, the study indicates areas requiring improvement, including adopting more efficient IT systems to increase picking accuracy and efficiency. Additionally, to maintain a high level of service quality, actions aimed at further route optimization and minimizing delays caused by external factors such as road traffic were recommended.

The results of this study provide valuable information for small and medium-sized industrial enterprises, emphasizing the importance of continuous assessment and optimization of logistic processes. Further research could explore innovative solutions and technologies to meet identified challenges and further increase efficiency and customer satisfaction in order picking and transportation operations.

Throughout the order picking process, individual activities were identified to pinpoint those negative activities that do not bring the expected value.

A limitation of the study was the analysis conducted in only one company. A comparative analysis should be conducted in at least several manufacturing enterprises within the same sector. Proposed improvements can only be verified after a certain period has elapsed since their implementation. The proposed modifications will not only streamline the organisation of order picking and transportation but also increase efficiency, reduce costs, strengthen the company's position in the industry, and most importantly, impact customer satisfaction. Therefore, further research in this area is planned for the future.

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