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Identification and Minimization of Risks in the Logistics Processes of a Window Blinds Manufacturing Company Using PHA and TPM

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Abstract:

Purpose: *The purpose of this study is to identify and evaluate risks in the logistics processes of a window blind manufacturing enterprise and to propose improvement measures to minimise their impact. The research focuses on internal and external determinants affecting logistics efficiency, with particular attention to warehouse management, inventory planning, and distribution. The study also assesses the potential of integrating Preliminary Hazard Analysis (PHA) with Total Productive Maintenance (TPM) to enhance operational stability.*
Design/Methodology/Approach*: The research was conducted in a Polish manufacturing company during 2024. Data were collected through employee questionnaires, interviews, direct observation, and PHA-based risk assessment. Ten employees participated in the survey, assessing both the probability of risk occurrence and the severity of consequences across procurement, storage, inventory management, production, and distribution stages. TPM principles were then conceptually applied to the identified risk areas. A comparative analysis was carried out to evaluate risk levels before and after the introduction of proposed improvements.*
Findings: *The results revealed critical risks in warehouse logistics, including insufficient storage space (R=24.0), loss of stock (R=24.0), and delays in customer deliveries (R=24.4). Inventory management issues such as inaccurate demand forecasting (R=18.8) and excessive stock (R=15.2) were also identified as major threats. The application of TPM in combination with PHA reduced the overall risk level by approximately 46%, with the most significant improvement observed in the area of warehouse space management (−65%). After implementing corrective actions, most risks shifted from "unacceptable" to "tolerable" levels.*
Practicaal implementations: *The study provides actionable recommendations for manufacturing enterprises operating under resource and space constraints. Key proposals include warehouse reorganisation and expansion, adoption of automated inventory*

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management systems, real-time monitoring of supplies, and the integration of TPM practices with systematic risk assessment tools such as PHA. These measures improve logistics continuity, reduce operational costs, and enhance customer satisfaction.
Originality/Value: *This research contributes to the limited body of knowledge on risk management in the window blind manufacturing sector. By demonstrating the combined use of PHA and TPM, the study introduces a practical framework for systematically identifying and mitigating logistics risks. The findings hold value for both scholars and practitioners seeking to strengthen process reliability and competitiveness in small and medium-sized enterprises.*

Keywords: *Logistics risk management, window blind production, Preliminary Hazard Analysis (PHA), Total Productive Maintenance (TPM), inventory management, warehouse optimization.*

JEL codes: *L23, M11, O32.*

Paper type: *research article.*

1. Introduction

Efficient logistics management constitutes the foundation of operations for manufacturing enterprises, particularly within the window blind production industry, where the smooth flow of raw materials, effective inventory management, and timely delivery fulfilment play a crucial role. Rapidly changing market conditions, rising customer expectations, and the constant pressure to reduce costs necessitate the continuous improvement of logistics processes and the systematic identification of risks that may disrupt their proper course.

Accordingly, this study poses research questions concerning the nature and characteristics of risks occurring in logistics processes during the production of window blinds, the feasibility of implementing measures to minimize risk levels, and the effectiveness of the proposed improvements in mitigating their negative consequences. The answers to these questions carry cognitive value and practical, application-oriented significance for the enterprise under investigation.

A variety of methods were employed to achieve the research objective, enabling the collection of comprehensive data and an in-depth analysis of the problem. Questionnaires allowed for the acquisition of employees' opinions regarding their perception of risk, the identification of issues accompanying daily operations, and the evaluation of the effectiveness of existing risk management procedures.

The questionnaire design, encompassing both closed and open-ended questions, provided quantitative and qualitative information, which served as the basis for further analyses. Another method consisted of interviews with logistics managers, production supervisors, and quality specialists, aimed at deepening knowledge of risk identification, its impact on logistics processes, and the effectiveness of preventive measures. Direct discussions made it possible to obtain detailed insights and a better understanding of the organizational context.

Complementing these investigations were observations of logistics processes within the enterprise, covering the activities of teams engaged in warehousing, transport, and the production of window blinds. These observations facilitated the identification of problems complex to capture through surveys or interviews and allowed for the verification of previously collected data.

A vital tool applied in the study was the Preliminary Hazard Analysis (PHA) method, which enabled the systematic identification and assessment of risks associated with stages of logistics processes. Its application made it possible to detect potential problems early and plan actions to mitigate the effects of identified threats.

The combination of these research methods produced a coherent picture of risk within the logistics processes of a window blind manufacturing company. The integration of quantitative and qualitative data ensured the reliability of the analysis and allowed for the formulation of practical recommendations for process improvements. Consequently, the research findings contribute to advancing knowledge of risk management in logistics and serve as a foundation for managerial decision-making within the enterprise studied.

This article aims to identify key threats and factors determining the efficiency of logistics processes in a window blind manufacturing enterprise, as well as to develop proposals for corrective measures limiting their impact. The analysis takes into account both internal determinants resulting from the organization and structure of processes, as well as external factors linked to market conditions and the wider economic environment.

The research considerations are based on empirical data collected in the enterprise during 2024, from 1 January to 31 December, thereby capturing the dynamics of processes over the course of a year. The study focused on an enterprise located in Poland, which enabled the inclusion of the specific characteristics of the local market and industry. The scope of the analysis encompassed procurement, transport, warehousing, and distribution of finished products, as well as aspects related to quality control and after-sales service.

2. Literature Review

Logistics constitutes one of the key elements of business operations, directly influencing the timeliness of deliveries, cost optimisation, and the quality of customer service (Prokopenko *et al.,* 2021; Masłowski, 2021). Risk analysis in logistics processes enables the identification and resolution of issues related to warehousing, supply disruptions, or inadequate inventory management (Szymonik, 2024; Md Hanafiah, *et al.,* 2022). Understanding the sources of these threats and effectively minimising them is essential to ensuring the security and efficiency of production, particularly in manufacturing companies operating under conditions of increasing competition (Rath *et al.,* 2024.

The production of window blinds is closely linked to sectors characterised by marked seasonality and specific organisational requirements. In such an environment, risk analysis serves as a tool that allows for precise identification of problems within the enterprise and their consequences for organisational continuity.

The results of such research are not only of theoretical value but above all of practical significance, as they support the implementation of recommended solutions in practice. The proposed improvements can contribute to enhancing company performance, reducing operational risk, and strengthening competitiveness in the market.

In recent years, the external roller blind market has been marked by dynamic growth, driven by rising interest in products that combine functionality, aesthetics, and protective qualities. External blinds have become not only an architectural feature but also an important component of systems enhancing user comfort and safety by protecting against excessive sunlight, wind, or precipitation.

Contemporary market trends point to the growing popularity of technologically advanced solutions that increase product attractiveness through personalisation and integration with intelligent building management systems. Market forecasts confirm the steady growth of the sector – according to Transparency Market Research, between 2018 and 2026 the global market value of blinds is expected to exceed USD 92 billion, with an annual growth rate of 7.9%. Europe, with a share of around 43%, will remain the dominant market, generating a value of approximately USD 21.5 billion (https://www.budexpol…., 2024; https://newss.pl/…, 2024).

Positive trends are also observed in Poland, where in 2016 approximately 1.5 million blinds were produced with a total value of around PLN 440 million, of which more than half were exported (https://newss.pl/…2024; https://tusochaczew.pl/…2024). The growing demand for external blinds both domestically and abroad confirms the profitability of business operations within this market segment.

Of particular importance is the increasing significance of ecological and energy-related factors – customers are increasingly viewing blinds as an element that enhances the thermal insulation of buildings, thereby contributing to energy savings. A high degree of product personalisation, a wide range of materials and colours, as well as the implementation of innovative technological solutions, represent key determinants of market success for producers (https://newss.pl/…2024; https://www.ikmag.pl/….2024).

In business activity, risk is defined as the probability of incurring losses as a result of specific economic decisions (Basta and Lotfy, 2023). It encompasses situations in which certain variables are unknown or difficult to estimate, yet can be predicted through the analysis of recurring phenomena (Smid, 2012). Unlike uncertainty, risk refers to processes that can be modelled and assessed to some extent (Lejano *et al.,* 2021).

From a normative perspective, risk is defined as the impact of uncertainty on the achievement of objectives, understood as a combination of the probability of an event occurring and its consequences (Grzyl, 2013; Calabrese *et al.,* 2024). Although risk cannot be completely eliminated, appropriate management methods can reduce its negative impact on organisational performance, while at the same time using it as a stimulus for identifying areas in need of improvement (Rysińska-Wojtasik, 2018).

One of the significant sources of risk is delivery delays, which may be caused by internal factors, external conditions, as well as errors in information processes (Zhao *et al.,* 2023; Sanni-Anibire *et al.,* 2022). The most common causes include incomplete or incorrect delivery addresses, often resulting from imprecise completion of order forms by customers or inaccurate data provided to drivers.

Delivery timeliness is also negatively affected by failures of IT systems supporting logistics processes (Akturk *et al.,* 2022; Moh'd Anwer, 2022; Shan *et al.,* 2021). Integrated systems for route and operational data management, although they significantly improve the daily operations of logistics operators, remain vulnerable to technical disruptions that generate delays (Moh'd Anwer, 2022). Furthermore, technical problems in online shops, which prevent order placement or delivery scheduling, constitute an additional risk factor (https://trans-tok.pl/…2024).

A significant source of disruptions also lies in weather conditions (Lepage and Morency, 2021; De Winne and Peersman, 2021; Gössling *et al.,* 2023), including sudden snowfall, storms, or dense fog, which force carriers to modify routes or postpone delivery deadlines. The risk of delays additionally increases as a result of internal organisational shortcomings, such as failures in internal communication, stock shortages, or delays in deliveries from distributors to intermediate warehouses.

Order fulfilment times are also prolonged by the use of logistics models based on dropshipping, as well as by the necessity to meet minimum logistics requirements in wholesale orders (https://trans-tok.pl/…2024).

One of the key internal challenges faced by manufacturing enterprises remains the lack of sufficient warehouse space (Batarlienė and Jarašūnienė, 2024). The dynamic development of operations necessitates the optimisation of existing capacity in order to avoid the high costs associated with facility expansion or the rental of additional storage areas. Poor organisation of storage leads to operational disorder, errors in order picking, and extended order fulfilment times (https://www.mecalux.pl/…2024). For this reason, a well-structured and efficiently organised warehouse forms the foundation for improving the performance of the entire logistics system.

Of particular importance are ongoing inventory planning and regular stocktaking. Inadequate stock control, resulting from the manual maintenance of records based on paper documentation, leads to serious consequences such as product loss, errors in locating goods, and time-consuming searches for materials (https://dataconsult.pl/…2024).

An integral element of risk management in logistics is quality control, which ensures compliance of products with technical requirements and customer expectations (https://leanactionplan.pl/system…2024). Systematic inspection, testing, and monitoring of products at various stages of the production process enable the rapid detection of non-conformities and the implementation of corrective actions before the finalisation of the product (Stefanova, 2022; Tvoronovych *et al.,* 2024; Kryvoruchko *et al.,* 2021).

An effective quality control system reduces costs associated with complaints, repairs, and product replacements, while at the same time serving as a tool for the continuous improvement of production processes (https://sgpgroup.eu/…2024). Regular audits and quality tests guarantee the maintenance of high standards, which translates into increased customer satisfaction and loyalty, thereby strengthening the company’s competitive position (https://leanactionplan.pl/…2024).

2.1 Theoretical Approach to the Concept of TPM

Modern manufacturing enterprises, operating in conditions of growing competition and dynamic market changes, must seek new ways to increase efficiency, reduce losses, and ensure process reliability. One of the concepts that has gained particular recognition over the past decades is Total Productive Maintenance (TPM). It is a comprehensive philosophy of maintenance management and process improvement, whose main goal is to maximize the effectiveness of equipment by engaging all employees of the organization in maintenance, diagnostic, and improvement activities (Nakajima, 1988).

TPM originates from Japan, and its roots can be traced back to practices introduced in the 1960s at Nippondenso, where the idea of "productive maintenance involving all employees" was first applied. The concept was later developed and popularized by Seiichi Nakajima, whose 1988 publication is considered a seminal work in this field (Nakajima; 1988).

In the following years, TPM gradually spread across various industrial sectors, starting with the automotive industry and later expanding into the food, chemical, pharmaceutical, and electronics industries. The philosophy evolved and became integrated with other management systems such as Lean Management, Six Sigma, and TQM (Robinson and Ginder, 1995). Today, TPM is increasingly connected with the Industry 4.0 paradigm, using the Internet of Things, cyber-physical systems, and predictive analytics to forecast failures and optimize maintenance schedules (Lee *et al.,* 2015).

The essence of TPM is building an organizational culture in which responsibility for the technical condition of machines and the course of processes is borne not only by maintenance departments but by the entire organization – from operators through middle management to top executives. The concept relies on a coherent architecture that encompasses areas such as autonomous maintenance, planned maintenance, quality management, training, safety and environment, administrative support, focused improvement, and early equipment management (Ahuja and Khamba, 2008).

As a result, TPM becomes not only a set of technical practices but a holistic approach to production management. The effectiveness of TPM implementation is most often assessed using the OEE (Overall Equipment Effectiveness) indicator, which integrates three parameters: availability, performance, and quality.

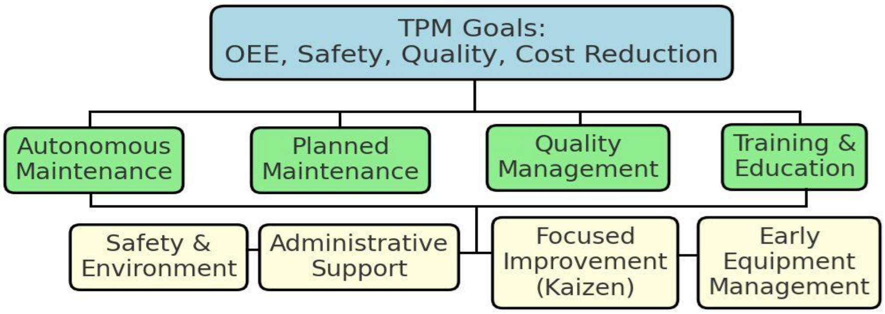
Research shows that systematic monitoring and improvement of OEE significantly reduces losses resulting from downtime, failures, and quality problems (Muchiri *et al.,* 2011). Experiences from various implementations confirm that a properly applied TPM system leads to higher equipment reliability, improved product quality, better resource utilization, and reduced operating costs.

It should be emphasized, however, that TPM implementation is not free of difficulties. The literature highlights numerous challenges such as high investment costs, the need for cultural change, employee resistance to taking on additional responsibilities, and problems resulting from a lack of adequate technical competencies (Deptuła *et al.,* 2024, Pradeep *et al.,* 2012). In industries with strict safety standards, such as the chemical or fertilizer sectors, an additional challenge is managing hazardous substances and ensuring strict compliance with legal regulations (Deptuła *et al.,* 2025).

Effective TPM implementation therefore requires a well-prepared strategy, strong managerial support, and a comprehensive training program. A holistic nature of TPM can be illustrated by its architecture, which is commonly represented as a structure supported by eight pillars (Figure 1).

These pillars include: autonomous maintenance, planned maintenance, quality management, training and education, safety and environment, administrative support, focused improvement, and early equipment management.

Figure 1. *Architecture of the TPM system*



Source: *Ahuja and Khamba (2008), Nakajima (1988), Robinson and Ginder (1995).*

Despite these barriers, TPM remains one of the most effective and universal methods of maintenance management, offering enterprises the possibility of significantly improving competitiveness and process stability.

The significance and practical possibilities of TPM implementation have been the subject of numerous research studies and case analyses across various industries. Norddin (Norddin and Saman, 2012) presented the application of the concept in a fertilizer plant, demonstrating that the system reduced the number of failures and the costs associated with unplanned maintenance.

Aspinwall and Maged (2013) pointed out that the most common problems in large and medium-sized enterprises are high implementation costs and low employee awareness. Similar observations were made by Jayathilake and Fernando (2025) who in a systematic review highlighted competency gaps and insufficient leadership as key barriers to successful implementation.

Slavina and Nedeljko (2024) noted that difficulties occur at all levels of hierarchy – from the introduction phase to long-term sustainability. In the studies of Panneerselvam (2012) and Prasanth *et al.* (2013), emphasis was placed on barriers typical of developing economies, such as lack of financial resources, low automation levels, and organizational problems.

The works of Ahuja and Khamba (2008) and Muchiri *et al.* (2011) are fundamental contributions to the TPM literature, pointing to the crucial importance of indicators such as OEE and the systematic analysis of losses. Bamber *et al.* (1999) showed that, in addition to technical aspects, organizational culture – particularly management involvement and transparent communication – plays a decisive role.

There are also many sector-specific analyses. Suresh (2012) applied the PDCA cycle in the food industry, highlighting the role of leadership and training in effective TPM implementation. Pradeep *et al.* (2012) developed a methodology for printing companies, while Ahmed *et al.* (2010) described a pharmaceutical case, where TPM contributed to efficiency gains and loss reduction. Tsang and Chan (2000) and Cooke (2000) analyzed TPM implementation in the context of organizational, financial, and political barriers, stressing that in traditional industrial structures, resistance to change is often the greatest challenge.

Modern approaches increasingly link TPM with digitization and Industry 4.0. Lee, Bagheri, and Kao (2015) described the architecture of cyber-physical systems enabling predictive maintenance, further enhancing the potential of TPM. Arromba *et al.* (2021) indicated that integration with new technologies requires additional investments in training and process adaptation, but at the same time provides greater opportunities to reduce risk and losses.

Comprehensive reviews also play a key role in understanding TPM. Marín-García *et al.* (2013) compiled barriers and enablers of TPM implementation, emphasizing that employee motivation, managerial commitment, and consistent strategy execution are essential determinants of success. Ireland and Dale (2001) compared three companies implementing TPM, demonstrating that top management support and consistency in applying the seven steps of autonomous maintenance are crucial for effectiveness.

Analyzing the literature, it can be concluded that TPM is a concept with a wide range of applications, effective in various industries and economic conditions. At the same time, however, it requires adaptation to organizational specifics and overcoming financial, organizational, and cultural barriers. Empirical research consistently confirms that TPM is an effective tool for reducing losses, improving quality, and ensuring reliability, although its implementation remains a demanding and long-term process.

3. Research Methodology

The study was conducted in an enterprise that has been operating on the market for nearly twenty-five years, specialising in the production of window blinds and gradually strengthening its position both domestically and abroad. The company, employing around ten staff members, achieves a monthly production output of between 50 and 100 units, depending on the season. Its product range includes a wide assortment, such as external blinds in surface-mounted, flush-mounted, and top-mounted variants, roller shutters, insect screens, as well as personalisation, installation, and maintenance services.

Customers are able to select parameters tailored to their individual needs, including colour, dimensions, type of drive, and control system. The production process encompasses the procurement of raw materials – including boxes, slats, strips, guides, and motors – followed by processing activities such as cutting, riveting, assembly, and installation of drives, and finally quality control and distribution of finished products. The average lead time for domestic orders is between seven and ten days, while foreign orders are fulfilled within ten to fifteen days.

In addition to its production activity, the enterprise operates a website that enables customers to configure products and cooperates with construction companies on large-scale investments. Internal logistics focuses primarily on the timely flow of materials between the warehouse and production, whereas external logistics encompasses direct deliveries to customers and the provision of installation services.

The main problem faced by the enterprise is limited warehouse space, which results in chaotic storage, difficulties in inventory management, and delays in order fulfilment. Consequently, this situation leads to increased operating costs and the risk of losing customer loyalty.

Within this article, five principal research methods were employed: questionnaires, employee interviews, direct observation, hazard analysis (PHA – Preliminary Hazard Analysis), and the proposed application of TPM (Total Productive Maintenance).

The choice of these methods was motivated by the need to gather reliable and diverse empirical data, enabling comprehensive identification and assessment of risks in logistics processes. A particularly significant aspect of the research process was the involvement of employees directly engaged in individual process stages, as their practical knowledge and experience allowed for the precise recognition of both the sources of risks and the potential areas requiring optimisation.

Questionnaires were one of the key research tools, enabling the collection of a wide spectrum of information from employees regarding their opinions, experiences, and perceptions of problems occurring within the enterprise. The questionnaire consisted of 13 open and closed questions, and a pilot study was conducted prior to the main survey to ensure clarity and precision of the questions.

The questionnaires were made available to all production employees of the enterprise (10 individuals) electronically via the company's e-mail and a dedicated platform, and their anonymous character enhanced the reliability of responses. The collected data were subjected to quantitative and qualitative analysis, organised in a spreadsheet for further processing.

Interviews were carried out to deepen the information obtained from the questionnaires. The focus was placed on employees' experiences and perspectives, as well as their assessments concerning risks, expectations, and everyday challenges in logistics processes. The interviews involved one production employee and one member of the management staff. The interview scenarios were based on issues identified in the questionnaires, and the conversations were conducted anonymously and at convenient times, with participants' consent.

Detailed notes were taken during the interviews, which ensured the credibility of the subsequent analysis. Observation was applied as a method enabling the systematic and purposeful recording of events and activities characteristic of the studied organisation. It allowed the actual course of processes to be captured while preserving the full authenticity of the data.

Thanks to observation, information obtained in questionnaires and interviews was verified, which facilitated a fuller understanding of the risks present. The study was carried out in a manner ensuring employee safety and without disturbing their natural work rhythm, so as to avoid bias in the results. The observation outcomes were carefully documented, analysed, and compared with the results of other methods.

In terms of risk analysis, the PHA method was used, which allows for the early identification of potential hazards at various stages of logistics processes, the assessment of the probability of their occurrence, and the consequences they may cause. The simplicity and flexibility of this method make it a useful tool for managing operational risk. As part of the procedure, questionnaires assessing individual company processes were carried out, and the results were compiled into tables for further analysis.

On this basis, hazards were identified using a risk assessment table and a risk acceptability matrix. These data enabled the creation of a control chart illustrating the level of risk at various stages of the logistics process. After proposing improvements, a follow-up questionnaire was conducted among employees, which allowed for a comparison of results and the evaluation of the effectiveness of measures taken to minimise risks.

The application of TPM in logistics risk management requires a theoretical foundation that links maintenance practices with broader approaches to identifying and mitigating risks. Cua *et al.* (2001) showed that Technical Performance Measurement (TPM) can function as a diagnostic tool in program and risk management by integrating technical metrics with probability-based assessments. This perspective emphasizes that TPM contributes not only to machine reliability but also to broader risk evaluation.

From a systemic viewpoint, Todinov (Ahuja I.P.S. 2009) argued that segmentation, permutations of operations, and reduced exposure in time and space are effective methods of lowering risks in complex logistics networks. Such ideas align with TPM, where diversified equipment use and process separation help prevent cascading failures.

Logistics networks face additional risks related to global supply chains. Gupta and Vardhan (2016) pointed out that collaboration and stable structures are crucial for mitigating disruptions in international container logistics. In parallel, Singh and Ahuja (2014) and Bhuiyan *et al.* (2024) highlighted the growing role of digital tools such as predictive analytics, digital twins, and sustainability strategies, which strengthen resilience when combined with TPM practices.

Risk is also shaped by external factors. Studies by Dmytryshyn *et al.* (2025), and Qazi (2022) applied Bayesian networks to show how country-level risks directly affect logistics efficiency. Such findings underline the need to integrate TPM with risk modeling beyond the factory level.

Technological solutions offer additional support. Skorna *et al.* (2009) demonstrated that telematics sensors improve monitoring and safety in transport logistics, while Enyejo *et al.* (2024) described how digital twins and predictive systems enhance risk control and sustainability. Yusri *et al.* (2025) and Oliveira *et al.* (2016) further showed how FMEA and Poka Yoke techniques can be applied in logistics to systematically identify weak points and reduce errors.

4. Research Results

4.1 Risk Analysis in a Selected Company – Interviews and Observations

The conducted research made it possible to collect data on the daily challenges in the area of logistics, including issues related to procurement, warehousing, inventory management, and distribution. Both open and closed questions were used, which enabled a quantitative and qualitative analysis of risk.

The aim of the research was not only to identify the main risks but also to determine which corrective actions and improvements could be implemented to minimise them. The collected data serve as a basis for further risk analysis and the development of proposals for optimising logistics processes.

The first survey question concerned the assessment of the efficiency of logistics processes within the enterprise. The results showed varied opinions among employees: 50% of respondents assessed the processes as “average”, indicating an acceptable level but with a clear need for improvements; 30% considered them “rather inefficient”, pointing to problems affecting production flow, delivery timeliness, and warehouse management; 20% rated them as “rather efficient”, noting well-functioning elements such as internal transport or cooperation with suppliers.

The absence of “very efficient” responses highlights that the company has not reached a model level, while the lack of “very inefficient” responses suggests that the existing problems do not completely disrupt operations.

The second question concerned the stages of the logistics process most exposed to risk. 90% of employees indicated material storage, confirming serious problems with warehouse organisation: insufficient space, improper layout of raw materials, difficult access, and risk of damage. 80% pointed to inventory management, where difficulties stem from forecasting errors, lack of automation, and problems in monitoring stock levels, leading to surpluses or shortages of raw materials and production delays. 40% of respondents identified procurement, noting difficulties with order specification and demand assessment, despite positive evaluations of suppliers.

Only 10% considered the delivery of finished products to be risky, suggesting that the main barriers occur earlier in the process. The absence of responses concerning order preparation and transport indicates that these stages are perceived as well-organised.

The third question addressed the impact of logistics risks (delivery delays, material damage) on production. 50% of employees stated that such situations occur rarely, indicating generally smooth logistics performance, although issues arise often enough to require attention. 30% noted that they occur occasionally, mainly due to shortages of unusual raw materials or components tailored to individual customer needs.

Although suppliers are positively assessed, difficulties arise from weak demand forecasting and inventory management errors. 20% reported no such experiences, signalling stability for standard orders. The lack of “frequent” responses suggests that problems are not systemic but rather the result of isolated cases and internal shortcomings.

The fourth question referred to the causes of delays in raw material deliveries. 70% of respondents indicated inefficient inventory planning, confirming problems with demand forecasting and the lack of a management system, particularly in the case of non-standard components. 50% pointed to shortages of raw materials on the market, indicating the influence of external factors on production. 20% mentioned transport problems, mainly related to long-distance deliveries or adverse weather conditions. 10% each pointed to supplier-related issues and warehouse infrastructure, which have less significance but stem from limited space and weak organisation. The results demonstrate that the main source of delays is internal shortcomings in planning and inventory management, with external factors also playing a role.

The fifth question concerned actions taken in the event of logistical problems. 70% of employees pointed to rescheduling production, usually due to shortages of non-standard raw materials, leading to delays and additional organisational burdens. 40% indicated prioritisation of deliveries, which helps protect key orders but may delay less urgent ones, damaging relations with smaller clients. 30% mentioned seeking alternative suppliers, which is applied as a last resort when the current supplier fails, but requires additional time for quality verification and negotiations, thus extending lead times. The results show that the company reacts flexibly, yet the solutions adopted carry the risk of further delays and process overload.

The sixth question referred to the frequency of delays in deliveries of products to customers. 70% of respondents stated that these occur frequently, mainly due to stock shortages, incorrect labelling, or chaotic records, which force additional orders and extend fulfilment. 20% indicated that delays occur very frequently, pointing to poor inventory management and the absence of modern stock monitoring systems, leading to incorrect forecasts and shortages. Only 10% reported that delays are rare, which confirms that smooth responses are the exception rather than the rule. The results clearly show that the main source of delays lies in ineffective warehouse and inventory management.

The seventh question related to the frequency of problems with raw material availability. 55.6% of respondents stated that such problems occur frequently, mainly due to warehouse shortages, errors in inventory management, difficulties in obtaining non-standard materials, and limited warehouse space. 44.4% noted occasional problems, indicating that the company usually ensures continuity of supply, though difficulties arise in the absence of a stock monitoring system. The lack of "rarely" or "never" responses confirms that the problem is widespread and requires corrective measures.

The eighth question asked about the adequacy of warehouse space. 50% of employees rated it as "rather insufficient", pointing to a lack of effective management and chaotic material storage. 40% considered it "definitely insufficient", confirming serious difficulties during peak production periods and problems with storing both raw materials and finished goods. Only 10% indicated "rather sufficient", suggesting partial adequacy with optimisation required. The absence of "definitely sufficient" responses clearly demonstrates that the current warehouse space does not meet the company's needs.

The ninth question addressed the assessment of procedures for preventing logistical risk. 60% of respondents deemed them sufficient but in need of improvement, especially in inventory management and warehouse organisation. 20% rated them as insufficient, indicating serious shortcomings in the risk management system, leading to delays and errors in order fulfilment. Only 10% considered them fully sufficient, which may reflect lower exposure to risk, while a further 10% had no opinion, suggesting insufficient awareness of the measures in place. The results indicate the need to optimise and refine procedures to more effectively minimise logistical threats.

The tenth question addressed the need to introduce additional tools and procedures in logistics risk management. 90% of respondents highlighted the necessity of automating inventory management through IT systems, which could eliminate warehouse chaos and the lack of stock information, often causing delays. 20% emphasised the importance of real-time supply monitoring, which would facilitate faster responses to problems. A further 20% indicated regular training in risk management, which would enhance employee awareness and competence. Only 10% considered the current tools sufficient, confirming the widespread need for changes and system modernisation.

The eleventh question concerned possible improvements to increase the resilience of logistics processes. All respondents (100%) identified better inventory planning as a key solution, confirming that inefficient stock management and shortages of raw materials are the main causes of delays. Additional proposals, such as audits and risk analysis, better use and expansion of warehouse space, or the implementation of inventory management systems, received 10% of responses each. Although less common, these suggestions indicate the need for a comprehensive approach combining warehouse organisation and modern technological tools. The absence of indications concerning flexible scheduling or communication with suppliers may suggest that these areas are viewed as less problematic or already functioning well.

The twelfth question asked about actions to improve the efficiency of logistics processes. Only half of employees provided answers, which may indicate difficulties in identifying solutions. The most common suggestions included better organisation and expansion of the warehouse, combined with the implementation of real-time inventory monitoring systems. Respondents also stressed the need for automation and the introduction of new technologies to reduce raw material shortages and improve responsiveness to order changes. The results clearly show that the key direction for development lies in improving warehouse organisation and adopting modern IT tools to support inventory management.

The thirteenth question addressed the impact of logistics process optimisation on the company's competitiveness. 90% of respondents agreed that improved logistics would enhance the enterprise's market position, while 10% expressed doubts but did not explicitly deny such an effect. The absence of "No" responses demonstrates a strong awareness of the importance of logistics in the company's operations.

The results and interviews underline the necessity of investment in optimisation, particularly in inventory management systems, warehouse expansion, and improved delivery scheduling. These measures can improve customer service, reduce costs, and strengthen competitiveness, while the high level of employee awareness supports the implementation of change.

Observations conducted in the window blind manufacturing company revealed significant logistics risks affecting efficiency and delivery timeliness. The key problem is insufficient warehouse space, especially during peak production periods, leading to chaos, inappropriate storage of materials, and risk of damage.

Additionally, shortcomings were noted in warehouse organisation, incorrect labelling, and difficulties in locating raw materials, all of which delay order fulfilment. In inventory management, frequent shortages of non-standard raw materials occur, caused by inefficient planning and the absence of systematic forecasting.

The lack of automation means the company does not have full visibility of stock levels, resulting in delays, production stoppages, and additional costs. The results indicate an urgent need for warehouse expansion and better organisation, as well as the implementation of modern inventory management systems, in order to increase continuity and efficiency in logistics processes.

4.2 Application of the PHA Method for Risk Assessment

In this analysis, risk was assessed on the basis of two criteria: the likelihood of its occurrence and the scale of potential damage, which made it possible to establish a risk hierarchy and to prepare recommendations for the optimisation of logistics processes.

Table 1. *Results of PHA analyses performed by employees (probability)*

Stage of the process	Probability of risk occurrence	1	2	3	4	5	6	7	8	9	10
Supply of raw materials	Delays in raw material deliveries	2	2	2	3	2	2	3	2	3	2
	Insufficient quantity of raw materials ordered	2	3	4	4	4	4	5	3	4	4
	Errors in the specifications of the materials supplied	1	2	2	3	2	2	2	2	2	3
Inventory management	Incorrect demand forecasting	4	3	4	3	3	5	5	5	4	4
	Loss of inventory in the warehouse	5	5	4	5	5	6	4	5	5	4
	Excessive inventory	3	3	4	4	4	5	5	4	4	4
Storage of raw materials	No storage space	5	4	6	5	5	6	4	5	5	6
	Damage to raw materials during storage	2	2	2	2	3	3	2	2	2	3
	Incorrect labeling of raw materials	4	4	6	4	4	3	5	5	5	5
Internal transport	Collisions during internal transport	2	1	2	1	1	2	1	1	2	1
	Delays in the delivery of raw materials to workstations	1	2	3	3	3	2	2	2	3	3
	Damage to raw materials during transport	1	2	3	2	2	1	2	2	2	2
Production	Lack of raw materials at workstations	4	4	3	4	4	4	3	4	3	3
	Machine failure	1	1	2	2	2	2	2	2	2	2
	Low productivity due to staff shortages	1	1	2	1	1	2	2	1	2	1

Distribution and transportation	Delays in deliveries to customers	4	4	5	5	5	5	4	4	5	5
	Errors in order picking	2	1	2	2	2	3	3	2	2	2
	Damage to products during transport	2	1	2	2	3	2	2	2	2	2

Source: *Own study.*

Table 2. *Results of PHA analyses performed by employees (effects)*

Probability of risk occurrence	**Effects**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Delays in raw material deliveries	Production downtime	2	2	2	3	2	2	3	2	3	2
Insufficient quantity of raw materials ordered	Delays in order fulfillment, additional costs for emergency deliveries	2	3	4	4	4	4	5	3	4	4
Errors in the specifications of the materials supplied	Production of incorrect products, complaints	1	2	2	3	2	2	2	2	2	3
Incorrect demand forecasting	Excess or shortage of inventory, leading to production downtime	4	3	4	3	3	5	5	5	4	4
Loss of inventory in the warehouse	Delays in production, the need to order missing raw materials	5	5	4	5	5	6	4	5	5	4
Excessive inventory	High storage costs, lack of storage space	3	3	4	4	4	5	5	4	4	4
No storage space	Organizational chaos, damage to materials	5	4	6	5	5	6	4	5	5	6
Damage to raw materials during storage	Material losses, production delays	2	2	2	2	3	3	2	2	2	3
Incorrect labeling of raw materials	Difficulties in locating materials, delays	4	4	6	4	4	3	5	5	5	5
Collisions during internal transport	Damage to materials, additional costs	2	1	2	1	1	2	1	1	2	1
Delays in the delivery of raw materials	Production downtime, decline in productivity	1	2	3	3	3	2	2	2	3	3
Damage to raw materials during transport	Material losses, the need to order additional materials	1	2	3	2	2	1	2	2	2	2
Lack of raw materials at workstations	Production downtime, delays in order fulfillment	4	4	3	4	4	4	3	4	3	3
Machine failure	Downtime, additional repair costs	1	1	2	2	2	2	2	2	2	2
Low productivity due to staff shortages	Delays in order fulfillment, decline in quality	1	1	2	1	1	2	2	1	2	1
Delays in deliveries to customers	Loss of customers, damage to the	4	4	5	5	5	5	4	4	5	5

	company's reputation										
Errors in order picking	Complaints, additional costs	2	1	2	2	2	3	3	2	2	2
Damage to products during transport	Complaints	2	1	2	2	3	2	2	2	2	2

Source: *Own study.*

Table 3. *Guidelines for adopting an indicator determining the likelihood of damage occurring*

Probability of damage occurring	
Description	**Indicator**
Very low (almost impossible, the risk is extremely rare)	1
Small (occasional, rare, once in a long time)	2
Medium (occurs with moderate frequency, predictable)	3
Large (occurs frequently, but not always)	4
Very high (risk occurs regularly)	5
Certain (every day, risk is almost always present)	6

Source: *Own study.*

Table 4. *Guidelines for adopting an indicator to determine the extent of damage*

Degree of damage	
Description	**Indicator**
Slight	1
Small	2
Moderate	3
Significant	4
Critical	5
Catastrophic	6

Source: *Own study.*

The table presents the results of the risk analysis carried out using the PHA (Preliminary Hazard Analysis) method, based on the assessments provided by ten employees of the enterprise. Each participant evaluated the probability of risk occurrence (P) and the severity of its potential consequences (S) at individual stages of the logistics process. These assessments were made in accordance with previously defined guidelines and scales.

Table 5. *Probability of risk occurrence*

Stage of the process	**Probability of risk occurrence**	**Level P (on a scale from 1 to 6)**
Supply of raw materials	Delays in raw material deliveries	2,3
	Insufficient quantity of raw materials ordered	3,7
	Errors in the specifications of the materials supplied	2,1
Inventory management	Incorrect demand forecasting	4,0
	Loss of inventory in the warehouse	4,8
	Excessive inventory	3,8
Storage of raw	No storage space	5,1

materials	Damage to raw materials during storage	2,3
	Incorrect labeling of raw materials	4,5
Internal transport	Collisions during internal transport	1,4
	Delays in the delivery of raw materials to workstations	2,4
	Damage to raw materials during transport	1,9
Production	Lack of raw materials at workstations	3,6
	Machine failure	1,8
	Low productivity due to staff shortages	1,4
Distribution and transportation	Delays in deliveries to customers	4,6
	Errors in order picking	2,1
	Damage to products during transport	2,0

Source: *Own study.*

The risk analysis carried out using the PHA (Preliminary Hazard Analysis) method enabled the identification and evaluation of hazards occurring at various stages of the logistics process in the window blind manufacturing company. The probability values (P) were determined on the basis of average scores provided by ten employees, who assessed the level of risk on a scale from 1 to 6, where a value of 1 corresponded to a very low probability of occurrence and a value of 6 indicated certainty of occurrence.

The analysis was divided into the key stages of the logistics process, including raw material procurement, inventory management, warehousing, internal transport, production, and distribution. The results show that, in the procurement area, the highest risk level (3.7) concerned insufficient quantities of ordered raw materials.

This situation suggests significant difficulties in demand forecasting, most likely resulting from limited access to precise data and insufficient use of tools supporting the procurement process. These issues lead to situations in which production must be halted due to material shortages. A moderate level of risk was recorded in the case of delays in raw material deliveries (2.3) and errors in material specifications (2.1), pointing to shortcomings in supplier communication and procurement organisation.

In the area of inventory management, the most pronounced risks were associated with the loss of materials in the warehouse (4.8) and inaccurate demand forecasting (4.0). These risks stem from the absence of automated stock monitoring systems and reliance on outdated or overly general planning data. The issue of excessive inventory (3.8) additionally burdens the enterprise by generating high storage costs, further limiting already insufficient warehouse space, and increasing the risk of damage or obsolescence of materials.

The most critical risk in the entire logistics process was identified in the area of raw material storage. Lack of warehouse space reached the highest risk value (5.1), indicating severe problems with space organisation. During peak production periods, materials are stored in unsuitable areas such as traffic routes or production zones. Additionally, a high level of risk was recorded in connection with improper labelling of materials (4.5), leading to difficulties in locating them and significant operational time losses. Damage to materials during storage (2.3) was assessed as a moderate risk, resulting from insufficient warehouse equipment and protective measures.

Internal transport was found to be the area with a relatively low level of risk. Collisions within the plant (1.4) and material damage during transport (1.9) were assessed as marginal phenomena, indicating good work organisation and compliance with safety rules. Only delays in delivering materials to workstations (2.4) pointed to the need to improve the synchronisation of material flows and the efficiency of internal transport means.

In the production area, the most serious problem was the lack of raw materials at workstations (3.6), a direct result of shortcomings in inventory management and inefficiencies in warehouse processes. Risks related to machine breakdowns (1.8) and staff shortages (1.4) were rated at a relatively low level, indicating appropriate organisation in technical maintenance and rational allocation of human resources.

In the area of distribution and transport, one of the most significant risks identified was delays in customer deliveries (4.6), often secondary to earlier problems in warehousing and inventory management. A moderate level of risk was identified in the case of order picking errors (2.1) and product damage during transport (2.0), both associated with insufficient supervision of packing and securing processes. The consequences of these issues include the need to handle complaints, prolonged order fulfilment cycles, increased operating costs, and the risk of reduced customer satisfaction and reputational damage.

In summary, the analysis demonstrated that the most critical risks to the stability of logistics processes result from insufficient warehouse space (5.1), loss of stock (4.8), and delays in customer deliveries (4.6). These are critical areas requiring priority improvement measures, including the expansion and better organisation of warehouse space, the implementation of modern inventory management systems, and the optimisation of distribution processes. Other risks, although assessed at a lower level, should also be subject to continuous monitoring and control to ensure the stability and reliability of the company's entire logistics system.

Table 6. *Results of PHA analyses performed by employees (effects)*

Probability of risk occurrence	**Effects**	**Level S (on a scale from 1 to 6)**
Delays in raw material deliveries	Production downtime	4,8
Insufficient quantity of raw materials ordered	Delays in order fulfillment, additional costs for emergency deliveries	4,3

Errors in the specifications of the materials supplied	Production of incorrect products, complaints	4,6
Incorrect demand forecasting	Excess or shortage of inventory, leading to production downtime	4,7
Loss of inventory in the warehouse	Delays in production, the need to order missing raw materials	5,0
Excessive inventory	High storage costs, lack of storage space	4,0
No storage space	Organizational chaos, damage to materials	4,7
Damage to raw materials during storage	Material losses, production delays	4,1
Incorrect labeling of raw materials	Difficulties in locating materials, delays	4,0
Collisions during internal transport	Damage to materials, additional costs	4,0
Delays in the delivery of raw materials to workstations	Production downtime, decline in productivity	4,5
Damage to raw materials during transport	Material losses, the need to order additional raw materials	4,0
Lack of raw materials at workstations	Production downtime, delays in order fulfillment	3,5
Machine failure	Downtime, additional repair costs	4,0
Low productivity due to staff shortages	Delays in order fulfillment, decline in quality	4,2
Delays in deliveries to customers	Loss of customers, damage to the company's reputation	5,3
Errors in order picking	Complaints, additional costs	3,7
Damage to products during transport	Complaints	4,2

Source: *Own study.*

The risk analysis conducted using the PHA (Preliminary Hazard Analysis) method made it possible to identify and evaluate hazards occurring at the individual stages of the logistics processes within the window blind manufacturing company. The level of consequences (S) was assessed on a six-point scale, where a score of 1 represented a minimal impact on the organisation's operations, while a score of 6 indicated the most severe consequences, potentially causing significant disruption to the company's functioning.

The consequence values (S) represent the average ratings provided by ten employees, who, drawing on their knowledge and experience, estimated the potential impact of risks on the company's operations.

In the area of raw material procurement, the highest consequence level was associated with delivery delays (4.8), which directly lead to production stoppages, order fulfilment delays, and potential customer loss. Insufficient quantities of ordered raw materials (4.3) result in the need for emergency deliveries, generating additional costs, while errors in material specifications (4.6) cause non-compliant production, material losses, and an increase in complaints, which in turn negatively affect the company's image and credibility.

In terms of inventory management, the most significant risks were related to misplaced materials in the warehouse (5.0), which may cause serious production stoppages and costly emergency orders. Inaccurate demand forecasting (4.7) was also identified as a considerable risk, leading both to excess stock—generating high storage costs—and to shortages resulting in production downtime. Excessive stock levels (4.0) additionally limit the already insufficient warehouse space and further reduce operational efficiency.

The most critical risk in the entire logistics process was identified in the area of raw material storage. Lack of warehouse space reached the highest risk value (4.7), resulting in organisational disorder, an increased risk of material damage, and delays in order fulfilment. Incorrect labelling of materials (4.0) caused difficulties in locating stock, while improper storage led to material losses, reflected in a risk score of 4.1 for storage-related damages.

Internal transport was found to involve moderate levels of risk. Delays in delivering materials to workstations (4.5) negatively affected process continuity and reduced efficiency. Internal transport collisions (1.4) and material damage during handling (4.0) were rated as marginal to moderate risks, though still associated with additional costs and potential production disruptions, especially in the case of high-value materials.

Within the production area, the most significant issue was the lack of materials at workstations (3.5), which directly caused stoppages that could only be mitigated through rapid response. Machine breakdowns (4.0) and reduced productivity due to staff shortages (4.2) were also identified as relevant risks, particularly likely to emerge during periods of increased demand.

In the area of distribution and transport, the most serious risks were related to delays in deliveries to customers (5.3), recognised as the greatest threat to the stability of business operations. These delays result not only in the loss of customers but also in reputational damage, which in the long term may weaken the company's competitive position.

Order picking errors (3.7) and product damage during transport (4.2) were assessed as moderate risks, negatively affecting operating costs and customer satisfaction, while also increasing the likelihood of complaints and additional organisational burdens.

In conclusion, the most significant consequences for the company are associated with delivery delays to customers (5.3), loss of stock in the warehouse (5.0), and insufficient warehouse space (4.7). These critical areas require priority improvement measures, including the expansion and better utilisation of warehouse space, the implementation of modern inventory management systems, and the streamlining of delivery planning.

The identified issues clearly indicate the need for systemic actions aimed at reducing risks and improving the efficiency of logistics processes, which in turn will enhance the company's competitiveness and operational stability.

Table 7. *Risk assessment table*

Stage of the process	**Probability of risk occurrence**	**Effects**	**Level P (on a scale from 1 to 6)**	**Level S (on a scale from 1 to 6)**	**Risk Level R (on a scale of 1-36)**
Supply of raw materials	Delays in raw material deliveries	Production downtime	2,3	4,8	11,0
	Insufficient quantity of raw materials ordered	Delays in order fulfillment, additional costs for emergency deliveries	3,7	4,3	15,9
	Errors in the specifications of the materials supplied	Production of incorrect products, complaints	2,1	4,6	9,7
Inventory management	Incorrect demand forecasting	Excess or shortage of inventory, leading to production downtime	4,0	4,7	18,8
	Loss of inventory in the warehouse	Delays in production, the need to order missing raw materials	4,8	5,0	24,0
	Excessive inventory	High storage costs, lack of storage space	3,8	4,0	15,2
Storage of raw materials	No storage space	Organizational chaos, damage to materials	5,1	4,7	24,0
	Damage to raw materials during storage	Material losses, production delays	2,3	4,1	9,4
	Incorrect labeling of raw materials	Difficulties in locating materials, delays	4,5	4,0	18,0
Internal transport	Collisions during internal transport	Damage to materials, additional costs	1,4	4,0	5,6
	Delays in the delivery of raw materials to workstations	Production downtime, decline in productivity	2,4	4,5	10,8
	Damage to raw materials during transport	Material losses, the need to order additional raw materials	1,9	4,0	7,6
Production	Lack of raw materials at workstations	Production downtime, delays in order fulfillment	3,6	3,5	12,6
	Machine failure	Downtime, additional repair costs	1,8	4,0	7,2
	Low productivity	Delays in order fulfillment,	1,4	4,2	5,9

	due to staff shortages	decline in quality			
Distribution and transportation	Delays in deliveries to customers	Loss of customers, damage to the company's reputation	4,6	5,3	24,4
	Errors in order picking	Complaints, additional costs	2,1	3,7	7,8
	Damage to products during transport	Complaints	2,0	4,2	8,4

Source: *Own study.*

Table 7 presents the results of the risk assessment for individual stages of the logistics processes within the company. The analysis was carried out using the PHA (Preliminary Hazard Analysis) method, which takes into account two key parameters: P (probability of risk occurrence) and S (consequences of risk). Both parameters were evaluated on a scale from 1 to 6, where 1 indicates a low risk and 6 denotes the highest priority level of risk.

The assessment was based on prior evaluations conducted by ten employees who, drawing on their professional experience, estimated both the probability of occurrence and the potential consequences of the identified risks. The values were then averaged to obtain an objective picture of logistical risk within the company. Based on this, and using the following formula, the risk level was calculated for each stage of the logistics process:

$$\text{Risk Level (R)} = \text{Probability (P)} \times \text{Consequence (S)} \quad (1)$$

Based on the results of the analysis, the risk assessment matrix and the risk acceptability table confirm the existence of unacceptable risks with a value of $R \geq 12$. These are mainly risks related to:

- warehouse logistics (lack of space, loss of inventory);
- production planning (incorrect demand forecasts, lack of raw materials);
- customer deliveries (delivery delays).

The identified risks require immediate corrective action to reduce their likelihood or impact in order to ensure the smooth functioning of the organization and avoid financial and reputational losses.

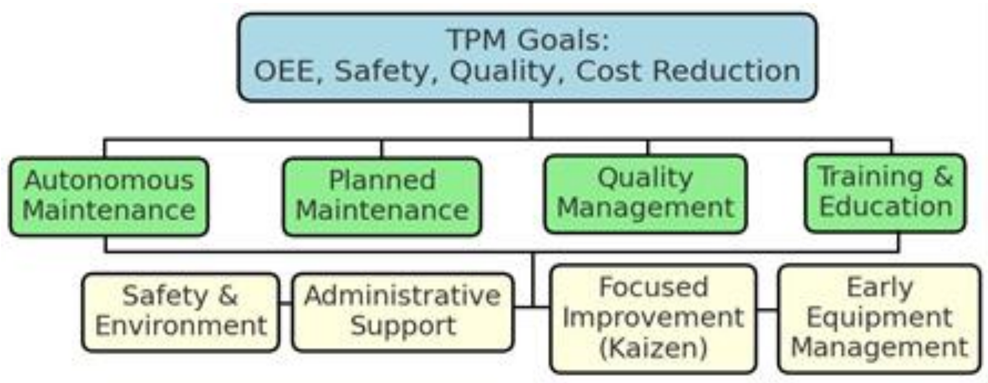
The risk level control chart was created to visualize and analyze the risks identified at each stage of the logistics process. The chart shows the risk values R, calculated based on the probability of an event occurring and its potential consequences, and three levels of acceptability.

When analyzing the chart, it can be seen that several stages of the logistics process exceed the value of $R \geq 12$, which means that the risk is unacceptable. The highest values occur in stages related to lost inventory (R=24), lack of storage space (R=24), incorrect labeling of raw materials (R=18), delays in deliveries to customers

(R=24.4), demand forecasting (R=18.8), excessive warehouse stocks (R=15.2), insufficient orders (R=15.9), and lack of raw materials at workstations (R=12.6).

These stages are characterized by a high probability of problems occurring and their serious consequences for the functioning of the organization. Therefore, they require immediate corrective action.

Figure 1. *Risk level control chart*



Source: *Own study.*

It is also worth paying attention to stages where the risk level is within the tolerable range (5≤R≤11), such as specification errors (R=9.7), product damage during transport (R=8.4), and transport collisions (R=5.6). Risks in these areas need to be monitored to ensure that they do not exceed the unacceptable limit.

The chart also shows that there are no risk values within the acceptable range (R≤4) in the analyzed stages of the logistics process. This means that all identified risks have at least a moderate impact on the functioning of the organization and require specific actions.

In summary, the chart and risk acceptability tables indicate the need to prioritize areas of unacceptable risk while monitoring tolerable risk. These actions will minimize potential disruptions to the logistics process and limit their negative effects.

5. Discussion

The risk assessment carried out using the PHA (Preliminary Hazard Analysis) method enabled the identification and evaluation of hazards occurring at individual stages of the logistics processes in the window blind manufacturing company. The level of consequences (S) was assessed on a six-point scale, where a score of 1 denoted a minimal impact on the organisation's operations, while a score of 6 indicated the most severe consequences, potentially causing significant disruption to the company's functioning.

The consequence values (S) represent the average ratings provided by ten employees, who, drawing on their professional experience and knowledge, estimated the potential impact of risks on the company's operations.

In the area of raw material procurement, the highest consequence level was associated with delivery delays (4.8), which directly lead to production stoppages, delays in order fulfilment, and potential customer loss. Insufficient quantities of ordered raw materials (4.3) resulted in the need for emergency deliveries, generating additional costs, while errors in material specifications (4.6) led to non-compliant production, material losses, and an increase in customer complaints, thereby negatively affecting the company's image and credibility.

Within inventory management, the most significant risks were linked to the misplacement of materials in the warehouse (5.0), leading to serious production stoppages and costly emergency orders. Incorrect demand forecasting (4.7) was also identified as a major risk, as it caused both excessive stock – generating high storage costs – and shortages leading to production interruptions. Excessive stock levels (4.0) further restricted limited storage space and reduced operational efficiency.

The storage of raw materials proved to be a particularly problematic area in terms of risk consequences. Lack of warehouse space was assessed at 4.7, leading to organisational chaos, increased risk of material damage, and delivery delays. Incorrect labelling of materials (4.0) caused difficulties in locating them, while improper storage led to material damage, reflected in a risk score of 4.1 for storage-related losses.

Internal transport was characterised by moderate risk levels. Delays in delivering materials to workstations (4.5) negatively influenced process continuity and reduced efficiency. Internal collisions (1.4) and damage to materials during handling (4.0) were considered marginal to moderate risks, though they still generated additional costs and could disrupt production, particularly when high-value materials were involved.

In the production area, the most significant issue was the lack of raw materials at workstations (3.5), directly causing stoppages that could only be mitigated through rapid intervention. Machine breakdowns (4.0) and reduced efficiency due to staff shortages (4.2) were also identified as relevant risks, especially during peak demand periods.

The highest consequence levels were identified in the area of distribution and transport. Delivery delays to customers, rated at 5.3, were recognised as the most severe threat to the stability of the company's operations. The consequences include not only the potential loss of customers but also a decline in the company's reputation, which in the long term may weaken its market position.

Order picking errors (3.7) and product damage during transport (4.2) were assessed as moderate risks, negatively affecting operating costs and customer satisfaction, while also increasing the likelihood of complaints and additional organisational burdens.

In conclusion, the most critical consequences for the enterprise are associated with delivery delays to customers (5.3), the misplacement of stock within the warehouse (5.0), and insufficient warehouse space (4.7). These areas require priority optimisation measures, including the expansion and better organisation of warehouse space, the implementation of modern inventory management systems, and the improvement of delivery planning. The identified problems clearly highlight the need for systemic action aimed at reducing risks and enhancing the efficiency of logistics processes, which in turn will contribute to increased competitiveness and the long-term stability of the company.

Table 7 presents the results of a risk reassessment based on evaluations made by employees after the implementation of the proposed improvements. The purpose of this analysis was to examine the effectiveness of the corrective measures introduced in areas of risk previously considered unacceptable.

Employees assessed the likelihood of risks occurring and their potential impact in the context of improved processes and solutions implemented. These assessments made it possible to verify whether risk levels had been reduced to acceptable or tolerable values.

These results will serve as the basis for developing an updated risk matrix and control chart, enabling further monitoring and risk management within the organization.

The analysis shows that the implemented improvements have effectively reduced the level of risk in many areas, with most falling within the tolerable range.

The chart shows the variability of the risk level (R) for individual stages of the logistics process, both before the implementation of improvements (Risk level - Previous) and after their implementation (Risk level - Current).

Table 7. *Risk assessment table after improvement*

Stage of the process	Probability of risk occurrence	Effects	Level P (on a scale from 1 to 6)	Level S (on a scale from 1 to 6)	Risk Level R (on a scale of 1-36)

Supply of raw materials	Insufficient quantity of raw materials ordered	Delays in order fulfillment, additional costs for emergency deliveries	2,3	4,1	9,4
Inventory management	Incorrect demand forecasting	Excess or shortage of inventory, leading to production downtime	2,5	3,8	9,5
	Loss of inventory in the warehouse	Delays in production, the need to order missing raw materials	2	4,7	9,4
	Excessive inventory	High storage costs, lack of storage space	2,6	4	10,4
Storage of raw materials	No storage space	Organizational chaos, damage to materials	2,1	4	8,4
	Incorrect labeling of raw materials	Difficulties in locating materials, delays	1,9	3,8	7,2
Production	Lack of raw materials at workstations	Production downtime, delays in order fulfillment	2	5	10,0
Distribution and transportation	Delays in deliveries to customers	Loss of customers, damage to the company's reputation	2,3	5,1	11,7

Source: *Own study.*

Three levels of risk acceptability are taken into account, marked by lines:

- green line ($R \leq 4$) – acceptable risk that does not require additional action;
- yellow line ($5 \leq R \leq 11$) – tolerable risk, requiring monitoring;
- red line ($R \geq 12$) – unacceptable risk, requiring immediate corrective action.

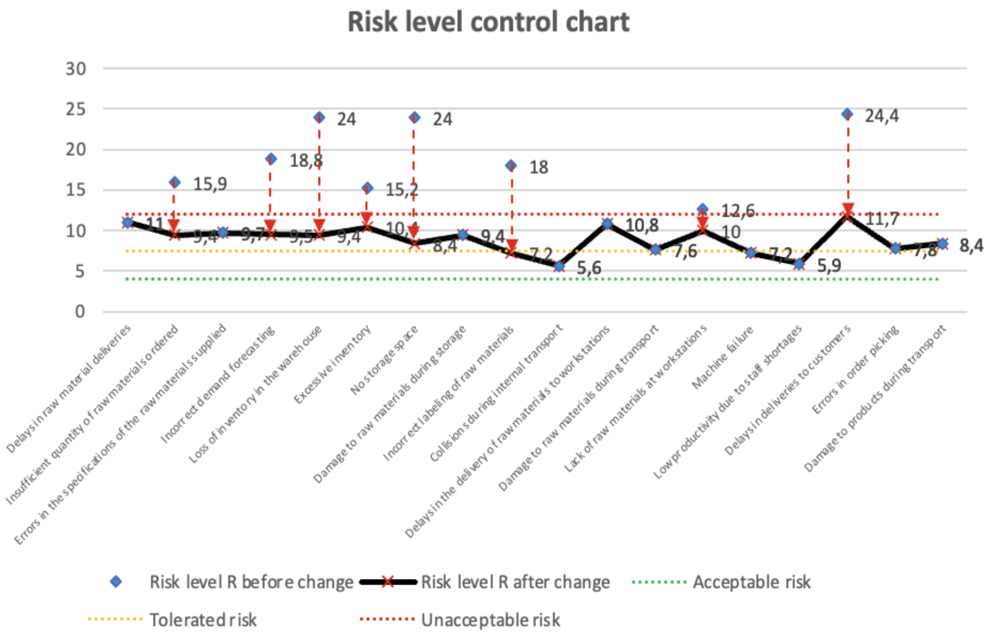
Points marked with a dotted line indicate the level of risk before corrective action is taken. In most stages of the process, the risk was in the unacceptable range ($R \geq 12$). These results indicate serious problems in warehouse logistics, production planning, and distribution. The solid line shows the level of risk after corrective measures have been implemented. A significant reduction in risk can be observed, which in most cases has fallen to a tolerable level ($5 \leq R \leq 11$):

- insufficient quantity of raw materials ordered fell from (15.9) to (9.4);
- incorrect demand forecasting decreased from (18.8) to (9.5);
- loss of inventory in the warehouse decreased from (24.0) to (9.4);
- excessive inventory decreased from (15.2) to (10.4);
- lack of storage space from (24.0) to (8.4);
- incorrect labeling of raw materials from (18.0) to (7.2);
- lack of raw materials at workstations from (12.6) to (10.0);
- delays in deliveries to customers were reduced from (24.4) to (11.7), but still require attention as they are close to the upper tolerance limit.

The chart clearly shows an improvement in the situation thanks to the implemented improvements. It also allows us to identify areas that require further monitoring and optimization in order to completely eliminate unacceptable risks in the future.

To evaluate the effectiveness of TPM in minimizing logistic risks, a simulation was carried out based on PHA data. Average values of P (probability) and S (severity) were taken from the survey results, and the risk indicator was calculated as R = P × S for eight key hazards. These results were then compared before and after TPM-driven improvements.

Figure 2. *Risk level control chart*

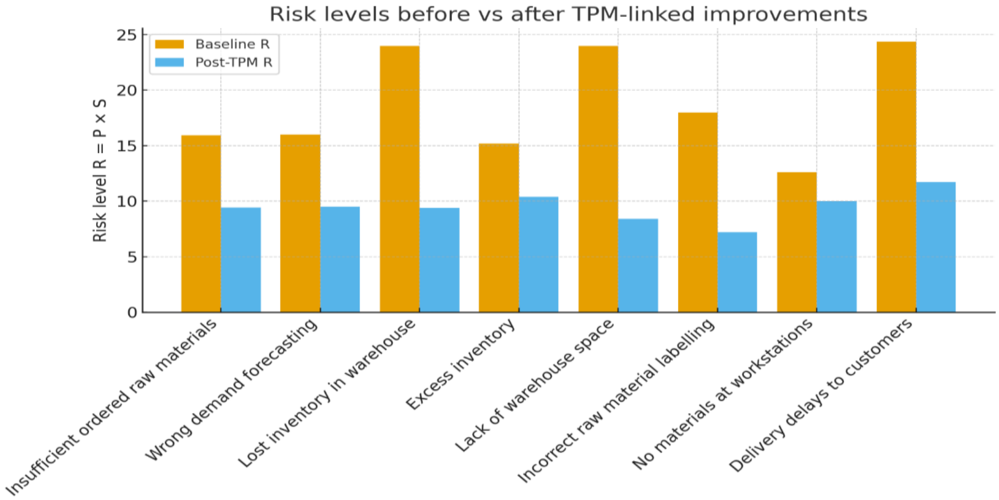


Source: *Own study.*

The findings (Figure 3) indicate that the average risk level decreased from 18.76 to 9.51, representing a reduction of approximately 46%. The largest improvement was observed for the hazard related to lack of warehouse space (−65%). As a result, several hazards shifted from the "unacceptable" risk band ($R \geq 12$) to the "tolerated" band, confirming the effectiveness of integrating TPM with the PHA method.

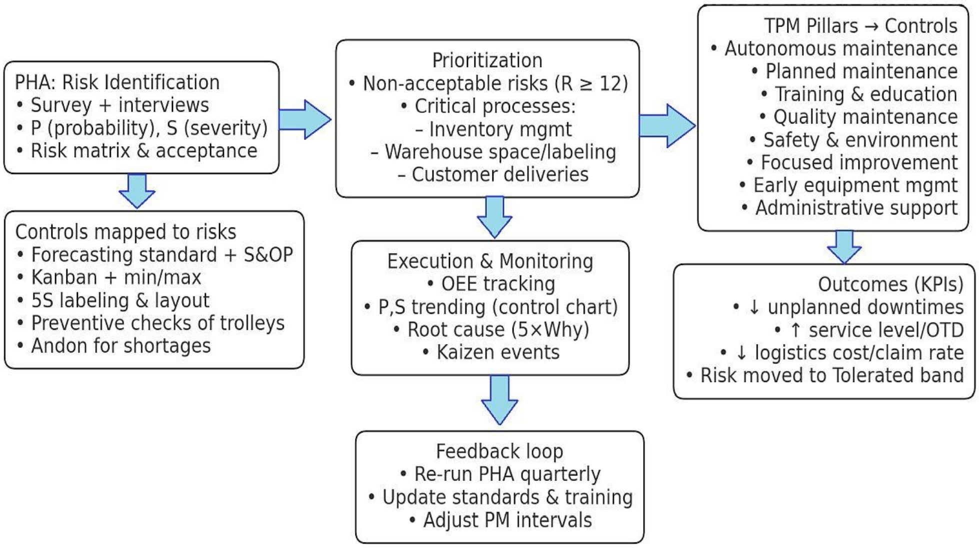
The second element is a conceptual model (Figure 4) illustrating how PHA can be directly linked to the pillars of TPM in the case of a window-blinds manufacturing enterprise. The scheme shows the progression from risk identification and prioritization (e.g., forecasting errors, excess inventory, delivery delays) through the selection of relevant TPM pillars (autonomous maintenance, planned maintenance, Kaizen, 5S, training), to execution and monitoring (OEE tracking, P and S trend analysis), and finally a feedback loop in the form of a repeated PHA cycle.

Figure 3. *Risk levels before vs after TPM-linked improvements*



Source: *Own study.*

Figure 4. *Risk levels before vs after TPM-linked improvements*



Source: *Own study.*

The quantitative analysis confirmed that applying TPM in combination with PHA significantly reduces logistic risks in the window-blinds manufacturing company. The average risk level decreased by nearly half, with several hazards moving from the "unacceptable" to the "tolerated" risk band. The proposed conceptual framework further demonstrates that effective integration of risk identification with TPM pillars strengthens not only equipment reliability but also the stability of the entire logistics chain.

6. Conclusions, Proposals, Recommendations

The research confirmed that the most critical risks in logistics processes of the analysed window-blind manufacturing company are insufficient warehouse space, loss of stock, inaccurate demand forecasting, and delays in customer deliveries. These factors directly influence production continuity, increase operational costs, and pose threats to customer satisfaction and market reputation.

The application of the PHA method enabled systematic identification and prioritisation of hazards, while the integration of TPM principles demonstrated that corrective measures can reduce risk levels by nearly 50%, shifting several risks from the "unacceptable" to the "tolerable" category. The study constitutes an original contribution by combining hazard analysis with TPM-driven improvements, offering a structured framework for reducing risks in small-scale manufacturing logistics.

The proposals developed in this study focus on strengthening logistics processes in the analysed enterprise and ensuring greater stability of operations.

First, warehouse optimisation and expansion should be undertaken through a reorganisation of storage systems, increased capacity, and the introduction of 5S practices, which would minimise operational chaos and reduce the risk of material losses.

Second, the implementation of automated inventory management systems is recommended, as digital tools enabling real-time stock monitoring and forecasting will effectively prevent shortages and excess inventory.

Third, the application of enhanced demand forecasting methods, supported by IT systems and historical data analytics, will significantly improve procurement planning and reduce disruptions in production.

Fourth, improvements in delivery scheduling are necessary, particularly by adopting TPM-linked procedures to synchronise production and distribution, which will limit delays and ensure higher customer satisfaction.

Finally, strong emphasis should be placed on employee involvement and training to embed the TPM culture in everyday practice, raise awareness of logistics risks, enhance competencies, and foster autonomous maintenance initiatives across the organisation. Together, these proposals constitute a coherent framework for minimising logistics risks and strengthening the company's competitiveness.

Future research should expand the scope beyond a single enterprise to include comparative analyses across different manufacturing companies and industries, which would allow for greater generalisation of results. Longitudinal studies could assess the long-term effectiveness of TPM-linked improvements and their sustainability over time.

Methodological extensions, such as integrating predictive analytics, digital twins, or Bayesian modelling, may further enhance risk identification and mitigation. Moreover, access to larger datasets from ERP or IoT systems would improve forecasting accuracy and robustness of the analysis.

In practice, companies should adopt a holistic approach by linking PHA with modern technologies and organisational culture changes, ensuring that logistics risk management becomes a continuous and adaptive process rather than a one-time intervention.

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