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IDENTIFICATION AND ANALYSIS OF DISRUPTIONS IN THE MATERIAL FLOW TO PRODUCTION PROCESS

Katarzyna DOHN[1*], Julia JURASIK[2]

[1] Silesian University of Technology; katarzyna.dohn@polsl.pl, ORCID: 0000-0002-4178-1347
[2] zj72@onet.pl
* Correspondence author

Purpose: The aim of this article is to introduce the concept of investigating disturbances in the flow of materials for production and to select methods that can be used to identify, measure and evaluate disturbances that occur in the material logistics of companies.
Design/methodology/approach: This paper proposes a self-developed methodology for identifying, measuring and analysing disruptions in material flows to the production process based on cause-and-effect analysis.
Findings: The result of the research undertaken in this article is to present the application of the developed methodology for the identification and analysis of disruptions in the material logistics of a paint and plastering compound company.
Practical implications: The developed methodology provides a versatile tool for identifying and analysing disruptions to material flows in the production process and can be applied to manufacturing companies in various industries.
Originality/value: This article contains the results of the measurement and analysis of disruptions occurring in the material flows of a company specialising in the production of paints and plastering compounds, for which an in-house methodology based on cause-effect analysis was proposed. This resulted in the identification of disruptions in material flows, but also in the identification of the source of their occurrence and where they manifest themselves in the value-added chain.
Keywords: material flows, disruptions, production process.
Category of the paper: Research paper, Case study.

1. Introduction

Materials logistics is the branch of science that deals with the management of the flow of materials within a company. Its main objective is to optimise and improve the way materials are moved, stored and used by a company. Within material logistics, the identification and analysis of disruptions in material flows plays a key role, as it allows the effective elimination of problems and the improvement of the efficiency of production processes. Maintaining a competitive edge in the face of a turbulent reality requires continuous improvement and the monitoring and reduction of events that cause deviations in the planned process flow.

Any delays in the execution of production orders in the construction chemicals industry, can postpone the progress of the schedule of construction investments for which the products were intended. Identifying material flow disruptions involves identifying, detecting and analysing any problems or events that may disrupt the continuity and efficiency of procurement and production processes. These can include delays in material deliveries, difficulties in inventory control, breakdowns of machinery and equipment, errors in production planning and many others. This article demonstrates the various methods and tools that can be applied in the identification of material flow disruptions and presents a three-step proposed methodology for identifying and searching for the sources of a company's problems.

The aim of the research carried out was to identify disruptions in the material logistics of a company producing paints and plastering compounds. A methodology for the identification and analysis of disruptions was proposed for such a research subject and the results of the research carried out in the selected production enterprise were presented. In relation to the selected objective, the events discussed in the literature that cause deviations were familiarised with in logistic processes and analysed methods of searching for their sources. The effectiveness of the presented methodology for identification and analysis of disturbances was compared with other methods available in the literature.

2. Literature background

In the face of today's challenges, it is essential to look for bottlenecks in the production process and minimise them. Organisations, especially industrial companies, are looking to save money and discover the potential of activities that could add more value to the company. Focusing on their internal processes, they first analyse material, information and financial flows (Makysova et al., 2024; Bulej et al., 2011; Bhamu, Singh Sangwan, 2014). In business practice, production and logistics companies have to solve a number of problems. Among the most common are (Hou et al., 2017; Islam, Huda, 2019): transport (choice of transport mode, choice of transport type, etc.), allocation (optimisation and distribution of products, distribution warehouses, optimisation of capacity utilisation, material handling), allocation (allocation of workers and machines), priorities (in orders, services), optimisation of loading operations and optimal use of resources.

Thus, when analysing the problems arising in the material logistics of an enterprise, it is necessary to take into account that the material flows used in the production of finished goods extend far beyond the framework of the production enterprise and involve a number of previous links in the supply chain (Bendkowski, Radziejowska, 2011). And the elimination of deviations can be carried out through the disposition of orders, material or technical parameters of operations, without changing the planned quantities. Another variant of activities that regulate the flow and aim to bring the expected volume into line with the achieved volume is the correction of accepted standards. Correction of the conditions of production process implementation is the most radical action aimed at changing the operational algorithm of production planning. Disturbances in such a complex production-logistics system are identified both at the input to the system and in the material flows in the system, as well as at the output from the system (Kramarz, 2012).

Disruptions to material flows are rarely discussed in the logistics literature. Most discussion in this area relates to the definition of risk in logistics processes (Kovacs, Tatham, 2009). Tang (2006) considers supply chain risk management (SCRM) as a collection of all types of events that can cause unplanned changes in the system, ranging from intra-organisational operational factors to random factors such as disasters, terrorism, etc. Similarly, other authors specialising in supply chain risk management consider a wide range of potential disruptions as sources of risk, but note that all such events require an extraordinary commitment of company resources (cf. Christopher, Peck, 2004). Dynamism, coupled with market volatility, continues to expose supply chains to disruptive events. The origins of these disruptions can be attributed not only to the complex, multi-tiered, and global nature of many supply chain configurations (Christopher, Peck, 2004; Jüttner, Maklan, 2011; Sheffi, Rice, 2005) but also to their inherent interconnectivity (Knemeyer et al., 2009; Bakshi, Kleindorfer, 2009). Consequently, supply chain disruptions are unavoidable occurrences, presenting a significant contemporary challenge regarding how organizations and their supply chains can recuperate while maintaining sustained performance outcomes (Ponomarov, Holcomb, 2009). This necessitates an enhancement in their ability to manage disruptions, thereby fostering and developing a resilient supply chain. Over the past decade, the resilience of organizations and their supply chains has garnered substantial interest from both practitioners and scholars (for a comprehensive review, see Tukamuhabwa et al., 2015). This heightened interest is driven by the profound impacts that disruptions can have at the firm level and beyond, affecting both short-term and long-term operational and financial performance (Hendricks, Singhal, 2005).

Taking into account all areas of the logistics process operation, failures can be divided into those that occur in the zone:

- procurement – resulting from collaboration with suppliers; related to delays, lack of communication, quantitative and qualitative errors in deliveries, volatility of material prices,
- production – due to lack of knowledge of process bottlenecks, lack of tools for planning and monitoring the production process, machine breakdowns, poor definition of customer needs or poor organisation of workstations,

- distribution – due to lack of adequate information on actual demand from points of sale, faulty forecasting methods, variability of demand, seasonality and trends, and market potential,
- transport – resulting from transport equipment failures, accidents, shortages of vehicles and drivers, inadequate means of transport, but also from transport system failures in the context of intra-company transport,
- warehousing – caused by poor organisation of warehouse space – lack of clearly separated zones for receiving storage and picking, lack of classification of materials, poor labelling of storage areas, shortage or excess of materials,
- supporting processes.

It should be noted, however, that each of these factors affects the business differently and not all of them will be recognised in every organisation. This list is not a closed set of issues, but rather outlines the areas around which they may fluctuate. They can all lead to a deterioration in customer service - delays in order fulfilment, damage to the company's image, loss of customers and weakened liquidity.

The problem of disturbance analysis is a multi-stage one and includes the identification of: the place where the disturbing factor appears (production line, workplace, supplier), the element that is the source of the disturbance (employee, means of transport, machine), the disturbance (difficulty in the functioning of the process: lack of employees, equipment, breakdowns, lack of materials, lack of information), deviations (as a consequence of disturbances), losses (related to the appearance of the deviation - extension of the production cycle, excessive stocks). On the other hand, disruptive factors are any unexpected events that have a disruptive effect on the system, causing a change in the state of the system in directions far from the state of equilibrium or the purpose of the activity (Kramarz, 2012).

3. Methodology

The activities of an enterprise are irrevocably linked to the constant cooperation, interactions and interactions between subsystems, departments and employees inside the organisation, but also with neighbouring links in the supply chain and stakeholders outside the system. The multiplicity of these interactions can provoke the emergence of conflicts, disrupt the smooth running of a given process and even go deeper, paralysing a wider range of processes carried out in active cells within the organisation. The most sensible way to counteract disruption is to eliminate the events that caused it. The different types of disruption and their most common causes have been recognised in the previous section, but their full identification for the unit under study, is a more complex process. In order to thrive in the current environment of intense market competition, companies need to be mindful of the increasing demands of customers to respond efficiently to their needs by delivering products according to the three principles of the '9W' logistics concept – at the right time, quality and price. In order to achieve the highest level of compliance with the above postulates, a company must first ensure the continuity and regularity of all processes directly and indirectly related to production. It was found that the efficiency of the core business of the studied organisation is affected by disruptions from the area of material logistics, which, by accumulating from the early stages of the procurement process, delay the delivery of products to final customers. It was decided to identify disruptions and wastage in the procurement and production processes of the selected enterprise, and to analyse the sources of their generation. A research procedure consisting of the following action plan was proposed:

1. Identification and quantification of disturbances – quantitative expression of the occurrence of disturbances

To ensure the best possible objectivity, reliability and completeness of the picture of the company's internal situation, it is suggested that data on disruptions be collected using social research techniques - employee interviews and surveys. Employees' views on disruptions and problems are important for building a culture of trust. Employees tend to have more information about daily operations and processes, so creating a space for dialogue and openness to their comments and suggestions improves understanding of the underlying problems that hinder their work and that of the plant as a whole.

A disruption measurement sheet was prepared for research purposes. The information contained in it should be selected on the basis of interviews (open questionnaire) with employees of sensitive departments of the organisation, such as logistics, procurement and production, and the so-called checklist containing a list of potential disruptions developed on the basis of literature research. It is only on this basis that a list of problems specific to the organisation and processes studied can appear in the interference measurement sheet. In the next step, the individual disturbances are subjected to an assessment of their frequency of occurrence in order to prioritise them later. The quantification of the studied phenomena is carried out by the employees, based on a five-point Likert scale, where 1 means very rare occurrence of a given obstacle - once a quarter and less often, 2 means occasional occurrence - once every two months, 3 means occasional occurrence - once a month, 4 means frequent occurrence - once every two weeks, and 5 means very frequent occurrence of a given obstacle - at least once a week. A model of the interference measurement sheet with examples of problems selected by employees is shown in Table 1.

Table 1.
Disturbance measurement card

Disturbance measurement card					
Process:	flow of materials for the production of paints and plasters				
Disturbances	**Frequency of occurrence**				
	Very rarely				Very often
Production equipment failure	1	2	3	4	5
Long-term/multiple retooling of the production device	1	2	3	4	5
Customer's withdrawal from the ordered goods	1	2	3	4	5
Change in the quantity/type of goods ordered by the customer	1	2	3	4	5
Overproduction	1	2	3	4	5
Production line stoppages	1	2	3	4	5
Lack of raw material for production	1	2	3	4	5
Incorrect placing of an order with the raw material supplier	1	2	3	4	5
Overflow of storage spaces for raw materials	1	2	3	4	5
Delay in the delivery of raw material	1	2	3	4	5

Source: own elaboration.

It should be noted, however, that the interview-based Disturbance Measurement Card reveals difficulties directly faced by employees, which may only indirectly contribute to the main problems reported by the organisation or its customers. Furthermore, they may interact, accumulate or have common causes.

2. Analysis of disturbances sources – Disturbance tree diagram

However, at the root of the diagnosed problems may lie non-obvious factors that are not apparent in the daily activities of the workplace and are overshadowed by their acute effects. Based on the 5WHY method, which helps to find the sources of waste by tracking down answers by successively asking the question "why" (Stoller, 2015), a fault tree diagram (Figure 1) was created, which shows the avalanche effect of the occurrence of a fault in a particular link of the process chain. This approach makes it possible to get to the source of the faults listed in the disturbance measurement diagram. At the top of the diagram is the effect of the partial failure – the main problem faced by the company, and the subsequent rows detail the intermediate events that led to its creation.

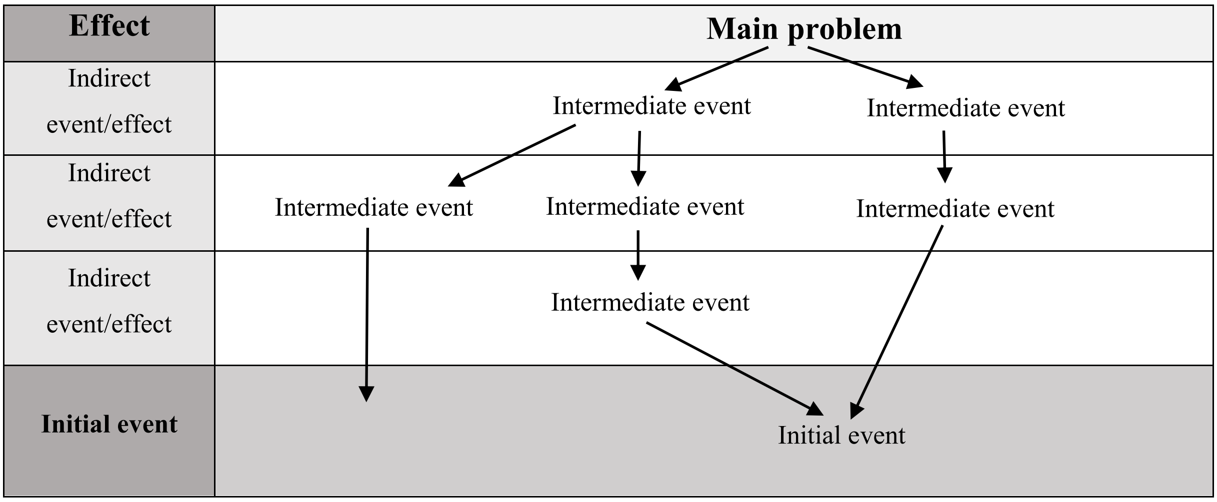

Figure 1. Disturbance tree diagram.

Source: own elaboration.

Having drawn up the above diagram, it can often be observed that the occurrence of a disturbance in one area/stage affects the deterioration of the situation in the following areas/stages, and that a given disturbance may have a multifaceted background.

3. Positioning the disruption in the value-added chain – Big Picture analysis

Value Stream Mapping (VSM, or Big Picture Analysis) has been suggested as a way to identify where the disruptions are occurring. This approach illustrates the flow of the entire process - from the supplier, through the manufacturing company, to the delivery of the product to the customer - and the associated information flows. On the big picture map, you can see where the problems diagnosed in the previous stage of analysis occurred, as well as activities that did not add value to the final product. It also helps to understand the relationships between different parts of the process and how they affect the flow of value. The map thus created is the starting point for identifying and eliminating activities, participants and objects that are responsible for process defects that do not add value, and for reducing the duration of those that remain essential (Dohn, 2004). This helps teams to understand exactly where to focus corrective actions.

4. Results

The research was carried out in a company belonging to the construction chemicals industry, which includes companies with similar needs - producing products for use in the wider construction market, where customers include individual customers as well as builders' merchants, wholesalers or renovation and construction companies. The selected company is a brand specialising in the production of facade and interior materials, in particular paints and plasters. Due to the diversity and complexity of the production processes in the company, the scope of the study was limited to the paint range. Production follows a similar sequence and is based on the same machinery for both paints, plasters and primers. Production starts according to the safety stock level set for each product, which is influenced by the demand forecast, the level of unfilled customer orders and the level of stock. The production of paints and other coatings consists of a series of repetitive operations based on batch processes. The operations performed in these processes are mainly mechanical in nature. In general, the production of waterborne paints involves dispersing and mixing bulk materials, including pigments and fillers, with an aqueous solution of additives.

The stability of the raw materials and the maintenance of the main supplier are of great importance for the reproducible quality and uniformity of the finished product. This is particularly important for the raw materials that form the basis of plaster products, where the slightest change in the source of the aggregate will alter the properties of the finished product. Due to the lack of natural sources of raw materials for the production of building materials in Poland, the company is forced to import some materials from abroad, including Italy, Germany and China. An analysis of the complaints of the customers of the interviewed company showed that most of the complaints addressed to the company were related to the failure to meet deadlines – delays in delivery. Deadlines are often not met. In addition, the company's employees pointed out the problem of overcrowded storage space for finished goods and the need to send surplus goods to a warehouse in Jaworzno up to twice a week. With the help of the interference measurement card, it was found that the most common errors hindering the employees' daily tasks were as follows:

- production equipment breakdowns, which occur on average once every two months,
- the hassle of retooling production machinery, which workers face every working week,
- overproduction, with quantities that cannot be used in the local warehouse,
- downtime on the production line - on average once every two weeks,
- delays in the delivery of raw materials, which occur on average once every two weeks.

These are priority issues for the company to focus on. However, as mentioned earlier, this survey is only a prelude to further analysis of the problems - it outlines the overall situation in the company. A fault tree diagram (Figure 2) was used to identify the source of the faults listed in the disturbance measurement sheet.

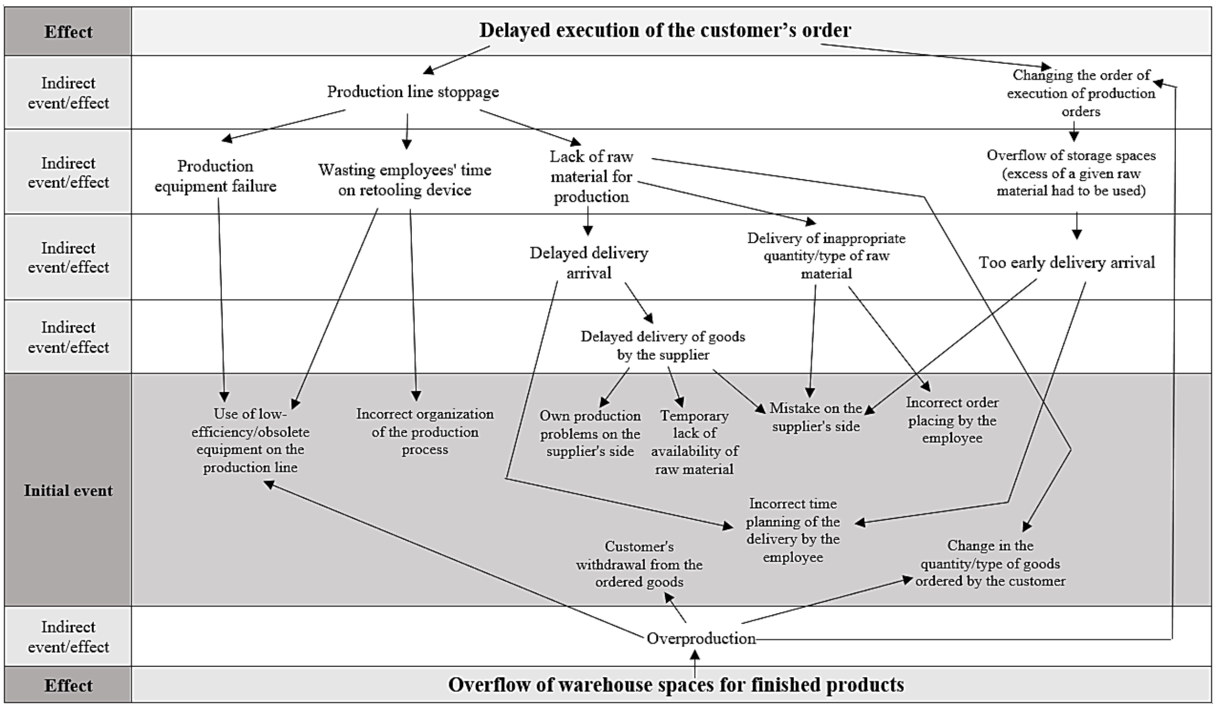

Figure 2. Disturbance tree diagram.

Source: own elaboration.

This method revealed the complex nature of the main problems. The two main dimensions of the sources can be traced back to supply logistics - most often inadequate quantity, type and timing of delivery - and production logistics, where efficiency and effectiveness are affected by the machinery used and the organisation of the production process. Errors made by employees at the stage of planning material requirements and placing orders with suppliers can result in production stoppages due to a lack of raw materials, which means wastage in the form of waiting times (for raw materials) and unused potential of employees or overflowing storage areas for materials. Changing the order of the production schedule in order to reduce stock levels avoids downtime, but often results in overproduction - unplanned production of products for which there is no demand at the time, while the customer waits for an outstanding order. On the other hand, the inconvenience of machine changeovers equates to wasted movement, transport and time within the changeover station.

Some of the sources of disruption are random and beyond the company's control - accidents, suppliers' own problems, customers' changing purchasing decisions. However, these are not analysed further because the company is unable to develop effective safeguards against them. It was found that placing the identified sources on the company's value stream map (Figure 3) would provide the most complete understanding of which areas, positions, equipment or stakeholders should be targeted for adjustments, corrective actions and improvements. In determining the times of individual operations in the production cycle, the average times for changeovers and transport of raw materials to dissolvers and mixers were also taken into account. The illustration of disruptions from suppliers and supply logistics shows that their occurrence affects the continuous flow of the remaining phases of the cycle. Dispersing and mixing equipment are involved in the rearmament activities. Raw materials are picked up, measured, delivered to the machines and filled into drums, all done manually by employees (except for pigment dosing, where a three-step dispenser is used, allowing precise dosing of the colour). Sources of disruption in the procurement subsystem are also found outside the organisation. Findings from employee interviews show that disruptions in the flow of information about the progress of orders to suppliers are a common situation. Some suppliers are more likely to experience delays in meeting commitments due to their own production problems or the distance between them and the organisation concerned.

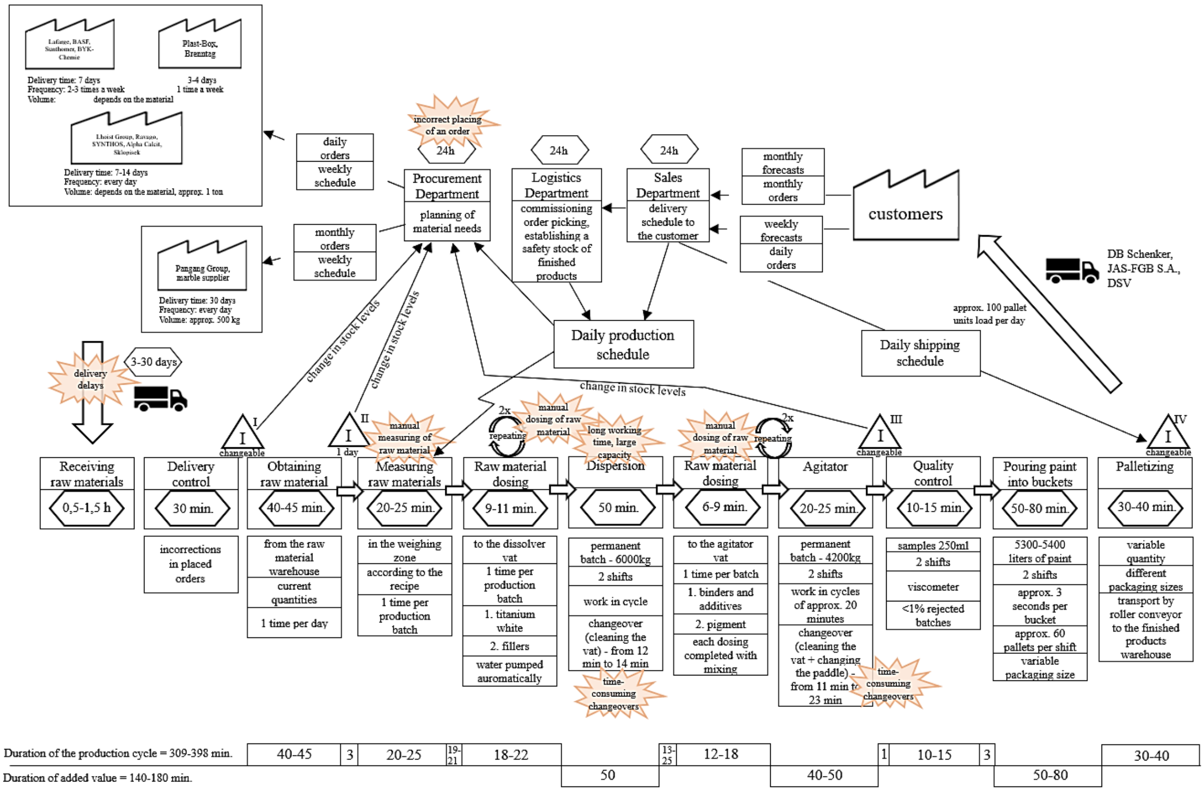

Figure 3. Big Picture map of the current state of material logistics flows in the selected company.

Source: own elaboration.

The map shown is a starting point for mapping the desired condition. Eliminating or correcting faults at the locations marked on the map will go a long way towards eliminating production line downtime and reducing customer service time.

It has been possible to tailor solutions and repair methods to the problems identified. A specific tool to reduce changeover times is SMED (Single Minute Exchange of Die), and it was decided to use it to redesign the production process flow. A supplier scoring exercise was carried out to verify which links at the top of the supply chain were responsible for delivery delays. In addition, the use of elements of the Poka Yoke philosophy in the ordering module of the ERP information system creates opportunities to eliminate human error at this stage of the material flow. The methods were chosen thanks to a careful analysis and localisation of disturbances in the company's process flow.

5. Discussion

Little research has been devoted to the consideration of effective methods for identifying problems in material flows and their causes. In the logistics literature, flow disturbances are usually discussed in the context of their impact on process continuity and considerations of their underlying causes. Little work has focused on identifying universal methods for identifying waste in processes and its causes. This is an area that requires further research and the development of specialised tools to effectively identify and understand the sources of disruptions.

Disturbances are events that cause deviations from the planned flow of materials. Disturbances can affect the quality, productivity and efficiency of processes, so their identification is critical for optimal system performance. The identification and analysis of disturbances is an integral part of process investigation and is critical to evaluating process performance and identifying areas for improvement.

In the work of S. Fox (1982) the idea of a procedure for the process of identifying disturbances appears, including:

- identifying the disturbances that affect the selected production process,
- definition of the frequency and probability of occurrence of the disturbance,
- comparative analysis of the impact of the disturbance on the process.

In their deliberations, the authors used a similar roadmap to draw up a list of priority disruptions for the company. However, at the stage of defining the disruptions, it was enriched with a questionnaire that made it possible to express precisely and quantitatively the problems directly encountered by the organisation's employees. However, it does not provide a full probabilistic analysis of the problems defined, but only a subjective expression of the frequency of occurrence of the irregularities listed.

Among the studies with topics that coincide with the objectives of this paper, one can find a multi-stage, cause-and-effect approach to the study of disruptions. Kramarz (2013) suggests that this analysis should start with the identification of irregularities in the material flow and then identify the relationship between the identified problem and its impact on the process. This research should eventually lead to the identification of the place where the disturbance occurs and the factor, the resource that causes it, which creates the conditions for assessing the total losses caused by its occurrence. This methodology was also used by the authors of this paper, where the cause-effect analysis, based on the 5WHY method, was visualised in the form of a fault tree diagram. Kramarz and Kmiecik (2017), on the other hand, presented the cause-effect relationship of the disruptions that occurred in the form of a disruption measurement sheet for each job (Table 2).

Table 2.
Disturbance measurement card

Date	Disruption	Reason descriptively	Entity responsible	The effect descriptively	Scoring of disturbances	
-	-	-	-	-	financial	organizational
	-	-	-	-	-	-

Source: Kramarz, Kmiecik, 2017.

Marecki and Pawlewski (2011), faced with the stochastic reality that surrounds the company, propose the use of problem solving techniques as a contrast to the analytical approach to problem solving that was the domain of the last century. Like the authors, Marecki and Pawlewski (2011) and Lis (1982) point to the crucial role of employees in identifying and investigating the causes of disturbances, as they have the most complete knowledge of the obstacle that has occurred.

As part of an effective system to support the detection of disturbances, they specify two groups of tools (Marecki, Pawlewski, 2011):

- theoretical, within which they list SPC (Statistical Process Control), FMEA (Failure Mode and Effects Analysis), QFD (Quality Function Deployment), Fish Diagram,
- creative: TRIZ (Theory of Inventive Problem Solving), USIT (Unified Structural Inventive Thinking), 5WHY, which partly overlap with tools attributed to the Lean Management philosophy.

The appropriateness of using the 5 WHY method for the problems encountered in paint production is confirmed by the areas of application suggested by the authors, which include "[analysing] deficiencies in process execution, [analysing] the causes of complaints".

In the past, however, tools based on a complex, multi-level analysis of the causes of the problem have already been developed. The exemplary USIT method, adopted in Japan in 1999 and based on the six-box system, is one way of creatively solving technological problems. It assumes that the diagnosis begins with the input of the problem from the user, who can be identified as an employee of the company. The problem should then be correctly defined, placed in the structure of the system in question and the target state defined, as is the case with the Big Picture Maps (VSM) used by the author.

The usefulness of the FMEA analysis cited by the authors is also recognised in the study by Kramarz and Kmiecik (2017), as another of the methods for clearly presenting the cause-and-effect relationships of the disruptions that have occurred. The authors emphasise the multifunctionality of the tool, which can be used both for projects aimed at validating newly manufactured products and for processes already implemented in the company. In the future, the FMEA tool could be used to evaluate the effectiveness of the preventive or corrective actions proposed by the author in relation to the defects that have occurred, by analysing their risk before and after the improvements.

A tool often used in research to analyse the causes of failure is the Ishikawa diagram. It can provide a graphical classification of the causes of a problem, in the dimension of five "M" (factors that can affect a problem) – man, machine, method, material, meter – as a cause-and-effect diagram. The summary of the analysis allows you to identify the main existing and potential sources of disturbance that have affected the outcome of the process under study.

Grabowska (2020), on the other hand, suggests using the A3 report to search for the root causes of previously diagnosed disturbances. This tool is characterised by its versatility, so it can be used for many purposes - solving predetermined problems, identifying those responsible for carrying out an activity, improving the effectiveness of organisational and employee learning, supporting continuous improvement within the company. The A3 report has a concrete structure that helps to understand and present the problem. It consists of sections such as a description of the problem, an analysis of the causes, objectives to be achieved and proposals for corrective action. However, the report itself is not an independent tool for investigating the causes of the problem, but relies on the methods already discussed - usually using one of the cause-effect analysis tools (Grabowska, 2020).

In the literature (Czabak-Górska, Kucińska-Landwójtowicz, 2015) one can also find an approach that uses statistical process control (SPC) – control cards – as a tool for detecting disturbances. When analysing control charts, it is important to identify the causes of all change signals in the processes under study, but this tool alone does not provide an answer to the question of where the problems originate. It only allows you to identify the occurrence of random errors, most of which are due to incorrect measurements. It can only provide a basis for finding their causes.

The methodology proposed by the authors can be applied to any area of the company's operations and is a universal tool for analysing the disruption of any process. Thanks to this approach, it is possible to act at the source of the problem, before it occurs, and prevent the generation of costs associated with the removal of the resulting "fires", often associated with the disruption of the continuity of plant operations. On the other hand, the proposed solutions to problems in the flow of materials into production itself depend on the nature of the problem and the industry/company in which it occurs. The research methodology adopted was an attempt to move away from methods based on intuition and guesswork, towards methods based on reliable information and practical knowledge from employees who were in direct contact with the problems that arose. The introduction of this methodology was aimed at increasing precision and objectivity in identifying problems and physically locating their causes in the value chain.

6. Conclusions

Disturbances are a common part of material flow. There are many factors that can cause disruptions in the flow channel. In order to formulate appropriate measures to mitigate the disruptions themselves and their negative effects, companies need to choose a methodology for their comprehensive analysis and evaluation.

Many types of disruptions to material flows have been identified in the literature, such as delays in the delivery of raw materials, errors in ordering, breakdowns in production equipment, imperfect design of the production process or problems with transport handling. Most of these fall into the category of organisation and management and are related to the most sensitive link in the whole process - the human factor and the system they design. In order to deal effectively with disruptions, it is essential to understand them, analyse their causes and how they arise.

The methodology proposed by the authors is based on existing, proven tools. It is based on a review of the literature on the material logistics of supply chain management and an analysis of the practices of various companies. The first step is to identify the main sources of disruptions in material flows. The second step is to analyse the location of these disturbances and their impact on the production process. This allows us to get to the root of the problems, to improve the factors that have disrupted daily operations, to give employees a voice, and to easily identify and locate problems in the company's material flow process.

References

1. Bakshi, N., Kleindorfer, P. (2009). Co-opetition and investment for supply-chain resilience. *Production and Operations Management, 18(6),* 583-603, https://doi.org/10.1111/j.1937-5956.2009.01031.x.
2. Bendkowski, J., Radziejowska, G. (2011). *Logistyka zaopatrzenia w przedsiębiorstwie*. Gliwice: Wydawnictwo Politechniki Śląskiej, p. 14.
3. Bhamu, J., Singh Sangwan, K. (2014). Lean manufacturing: literature review and research issues. *International Journal of Operations & Production Management, Vol. 34, No. 7*, pp. 876-940, 2014. https://doi.org/10.1108/IJOPM-08-2012-0315.
4. Bulej, V., Stoianovici, G.V., Poppeova, V. (2011). *Material flow improvement in automated assembly lines using lean logistics.* 22nd Annals of DAAAM & Proceedings, 23-26th November, Vienna, Austria, pp. 253-254.
5. Christopher, M., Peck, H. (2004). The five principles of supply chain resilience. *Logistics Europe, vol 12(1)*, pp. 16-21.

6. Czabak-Górska, I., Kucińska-Landwójtowicz, A. (2015). Identyfikacja zaburzeń procesu produkcyjnego w oparciu o analizę błędów grubych–studium przypadku. In: R. Knosala (ed.), *Innowacje w Zarządzaniu i Inżynierii Produkcji* (pp. 246-256). Opole: Oficyna Wydawnicza PTZP.
7. Dohn, K. (2004). Wykorzystanie analizy „Big Picture" do identyfikacji „wąskich gardeł" procesu produkcyjnego w przedsiębiorstwie. *Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie, z. 27, nr kol. 1681,* pp. 76-78.
8. Gaschi-Uciecha, A. (2015). Zakłócenia w procesach logistycznych przedsiębiorstw produkcyjnych – badania literaturowe. *Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie, z. 78, nr kol. 1928*, pp. 135-139.
9. Grabowska, J. (2020). Identification and analysis of potential disruptions in warehouse processes in the distribution centre of the food industry. *Science Journal of Warsaw University of Life Science. Economics and Organization of Logistics, 5(4),* pp. 21-30.
10. Hendricks, K.B., Singhal, V.R. (2005). An empirical analysis of the effect of supply chain disruptions on longrun stock price performance and equity risk of the firm. *Production and Operations Management, 14(1),* 35-52, https://doi.org/10.1111/j.1937-5956.2005.tb00008.x.
11. Hou, H., Chaudhry, S., Chen, Y., Hu, M. (2017). Physical distribution, logistics, supply chain management, and the material flow theory: a historical perspective. *Information Technology and Management, Vol. 18, No. 2*, pp. 107-117. https://doi.org/10.1007/s10799-015-0229-1.
12. Islam, M.T., Huda, N. (2019). Material flow analysis (MFA) as a strategic tool in E-waste management: Applications, trends and future directions. *Journal of Environmental Management, Vol. 244, No. X*, pp. 344-361 https://doi.org/10.1016/j.jenvman.2019.05.062.
13. Jüttner, U., Maklan, S. (2011). Supply chain resilience in the global financial crisis: An empirical study. *Supply Chain Management: An International Journal, 16(4),* 246-259, https://doi.org/10.1108/13598541111139062.
14. Knemeyer, A.M., Zinn, W., Eroglu, C. (2009). Proactive planning for catastrophic events in supply chains. *Journal of Operations Management, 27(2),* 141-153, https://doi.org/10.1016/j.jom.2008.06.002.
15. Kovacs, G., Tatham, P. (2009). Responding to disruptions In the supply Network – from dormant t action. *Journal of Business Logistics, Vol. 30, No. 2,* https://doi.org/10.1002/j.2158-1592.2009.tb00121.x.
16. Kramarz, M., Kmiecik, M. (2017). Pomiar zakłóceń w wybranym węźle dystrybucji. *Zeszyty Naukowe Politechniki Częstochowskiej Zarządzanie, No. 26.* Częstochowa, p. 182.
17. Kramarz, W. (2012). Model sterowania przepływami materiałowymi w sieci produkcyjnej. *Zeszyty Naukowe. Organizacja i Zarządzanie, no. 60.* Wyd. Politechniki Śląskiej, pp. 153-163.

18. Kramarz, W. (2013). *Modelowanie przepływów materiałowych w sieciowych łańcuchach dostaw. Odporność sieciowego łańcucha dostaw wyrobów hutniczych*. Warszawa: Difin, p. 76.
19. Lis, S. (ed.) (1982). *Rytmiczność procesu produkcyjnego. Zakłócenia i ich kompensacja*. Warszawa: PWE, p. 56.
20. Makysova, H., Galgoci, F., Babelova, Z.G., Starecek, A. (2024). The improvement of the production process performance through material flow and storage efficiency increases serial production. *Acta Logistica, 11(1),* 57-65. doi:https://doi.org/10.22306/al.vll1l.449
21. Marecki, M., Pawlewski, P. (2011). Wykorzystanie Problem Solving w skutecznym planowaniu w sterowaniu produkcją. In: P. Golińska (ed.), *Wybrane problemy logistyki produkcji* (pp. 149-150). Poznań: Wydawnictwo Politechniki Poznańskiej.
22. Ponomarov, S.Y., Holcomb, M.C. (2009). Understanding the concept of supply chain resilience. *The International Journal of Logistics Management, 20(1),* 124-143, https://doi.org/10.1108/09574090910954873.
23. Sheffi, Y., Rice, J.B. (2005). A supply chain view of the resilient enterprise. *MIT Sloan Management Review, 47(1),* 41-48.
24. Stoller, J. (2015). *Lean CEO. W drodze do doskonałości*. Warszawa: MT Biznes.
25. Tang, Ch.S. (2006). Perspectives in supply chain risk management. *International Journal of Production Economics, Vol. 103, Iss. 2,* pp. 451-488, https://doi.org/10.1016/j.ijpe.2005.12.006.
26. Tukamuhabwa, B.R., Stevenson, M., Busby, J., Zorzini, M. (2015). Supply chain resilience: Definition, review and theoretical foundations for further study. *International Journal of Production Research, 53(18),* 5592-5623, https://doi.org/10.1080/00207543.2015.1037934.