


Business Continuity Across Different Production Types and Forms: Lessons From a Crisis

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Abstract

The paper compares the results of protective measures used to maintain business continuity of Polish production enterprises during a crisis situation. It examines how these results differ depending on the type and form of production organization. A mix-model CATI/CAWI survey was performed on a representative group of 600 enterprises. Over 40 individual protection measures were identified and assigned to one of five predefined groups. The research specified three production types (unit/job, batch, mass) and two production forms (line production, job-shop production). A chi-square test was used for the statistical analysis. The results indicate that production volume, defined as the number of manufactured, repetitive products, affects the selection of protection measures. The production form, reflecting the way a product flows through the production process, is also significant. The findings provide a basis for future preparations aimed at ensuring business continuity in the event of similar disruptions to production processes.

Keywords

manufacturing enterprises, business continuity, protective measures, production types.

Introduction

The COVID-19 pandemic was officially recognized by the WHO on 11 March 2020 and has had an overwhelming impact on global society and the world economy. It has forced international organizations and governments to look for solutions to keep the various organizations whole under pandemic conditions. Guidelines from international organizations, for example (IFMA, 2020; ILO, 2020; OSHA, 2020), focus on personal and collective protection measures (masks, disinfection, social distance, separation partitions).

Many sectors of the economy have widely implemented solutions based on remote contact between people: education, administration, and services (banking, insurance, partly health, e-commerce). There have been publications on the organization of remote learning (Feghali & Offiler, 2021; Melnyk & Denzler, 1996; Mishra et al., 2020), office work modification towards

the use of remote working tools (Hou et al., 2021), work organizations in healthcare entities (Korneta et al., 2021; Kruszyńska-Fischbach et al., 2021; Özkan et al., 2021). It has already been noticed that the trend of moving towards remote working also continued in the post-pandemic period.

However, some sectors of the economy cannot move their activities online, including the transportation sector, the construction industry, a large part of health care, and most of all, the manufacturing industry. The main problem that affected manufacturing companies in the first period of the pandemic was maintaining business continuity due to the disruption of supply chains. A little later, there were internal causes due to the absence of employees due to COVID-19 illness, and the challenge became finding solutions to prevent the transmission and spread of the virus in the work environment. Comprehensive research has focused on finding strategic solutions for making businesses and supply chains more resilient to the negative phenomena associated with the COVID-19 pandemic (Belhaldi et al., 2021; Kumar et al., 2020; Lopez, 2022).

In recent years, the issue of pandemics has become increasingly significant for organizations. The COVID-19 pandemic has highlighted the reality that crisis situations are likely to occur more frequently, and many

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companies are unprepared to handle them. It is essential to learn from the experiences of recent years to better prepare for future crises – whether they are pandemics or similar challenges. By doing so, organizations can strengthen business continuity and minimize the negative impacts of such as events, which are important for organizations. The COVID-19 pandemic has made the world aware that crisis situations will become more frequent, and most companies are unprepared for them.

Margherita, A. & Heikkilä, M. (2021) surveyed 50 leading global companies based on secondary sources and identified activities connected with COVID-19 business continuity. They proposed a classification of these activities into five areas and related sub-areas:

1. Operation and Value System (Supply Chain Status, Logistic Flow In/Out, Manufacturing Processes)
2. Customer Experience and Support (Physical Interactions, Financial Assistance, Marketing Communication)
3. Workforce and Human Capital (Prevention Measures, Job Continuity/Productivity, Handling of Cases)
4. Leadership and Change Management (Crisis Management, Post-Emergency Value)
5. Community and Social Engagement (Donations and Support, Coordinated Actions)

Acciarini et al. (2021) discussed different business disruptions caused by Covid-19, and they developed an integrated policy framework in which they proposed specific strategic responses for increasing the level of organizational resilience: Financial Support, Sanitary Norms, Business Models/Business Systems, Digital Investment, Support to Education.

Pilot studies from 56 enterprises in Poland, analyzing conditions for supporting employee safety during the COVID-19 pandemic, are presented in Wronka (2023). These studies include conditions such as changes in the philosophy of the work, modifications in the organizational structure, new ways of communication, additional IT infrastructure, additional safety equipment, training on possible threats, training on changes and relations, expanded medical packages, increased employee benefits, financial allowances, workshops for employees, intensification of internal communication and others.

Studies of the resilience of supply chains to pandemic disruptions lead to the definition of common significant strategies: localized supply sources and industry 4.0 technologies. These two directions have been confirmed in studies (Sajjad, 2021; Schleper et al., 2021). Belhadi et al. (2021) added real-time information sharing to these factors. Bryce et al. (2020) additionally point out that over-reliance on the benefits of lean manufacturing has yet to work well under pandemic conditions.

Many studies emphasize the importance of digitized Industry 4.0 solutions, replacing high-risk human labor for virus transmission, such as Robots, Cyber-physical systems, Artificial Intelligence, 3D printing, Digital Twin, Blockchain, etc. for the production of goods (Kumar et al., 2020). Research presented by Shen et al. (2021) confirms that many companies have recently implemented or intend to implement robots and robotic systems to overcome the challenges of the pandemic. The study Siderska (2021) shows that almost 60% of the respondents indicated that robotization tools allowed for maintaining the continuity of business processes during the pandemic.

Sneddon (2021) believes that using standard risk management methodologies can help better understand the pandemic as a risk to the organization's business continuity and ensure the measures in place to manage said risk are appropriate and effective. Hofbauer & Quirchmayr (2021) propose a systematic approach to building operational resilience. However, both of these approaches take time and can be helpful in preparing an organization for future pandemic crisis events.

The research project: *Models of the adaptation of work organization in enterprises to the limitations of public life (associated with a pandemic) in line with the demands of business effectiveness and efficiency*, was carried out at the Warsaw University of Technology at the Faculty of Management for more than two years. It aimed to propose model organizational solutions at the operational level, improving industrial enterprises' ability to ensure business continuity under pandemic conditions.

It is worth mentioning that the project conducted, among other things, studies of the impact of the COVID-19 pandemic on economic prosperity. Using data from 176 countries, negative and statistically significant correlations were found between COVID-19 mortality rates and changes in GDP. The economies of individual countries were shown to become more resilient to the pandemic as the pandemic progressed, demonstrating that economies develop resilience to the adverse effects of COVID-19 that results from both government action and the agility of businesses and societies (Korneta & Rostek, 2021). Work has also been conducted on mathematical modeling of pandemic development. It was shown that the multi-logistic function developed for forecasting pandemic development using logistic wavelets approximates the results well (Rządkowski & Figlia, 2021). How the number of tests performed affects COVID-19 morbidity and mortality in different countries was investigated. Optimal levels of testing were identified due to cost and health (morbidity/mortality) aspects. Recommendations were indicated for the three identified testing ranges, depending on a country's financial and operational capabilities (Korneta et al., 2021).

Filling a gap in the existing literature, this study stands out for its unique, multi-level approach to analyzing organizational resilience. While existing literature has predominantly approached the manufacturing sector as a monolithic entity, it has frequently overlooked the nuanced differences inherent in distinct process organizations. In contrast, the present work focuses on the operational level, moving beyond general supply chain strategies to perform a detailed stratification and structural segmentatscope of solutions based on production types and forms. The study integrates rigorous statistical modeling with a direct analysis of organizational practices based on a representative sample of manufacturing enterprises. The breadth of the survey research facilitated a comprehensive identification of organizational responses and the proposition of mature adaptation practices. These practices serve two primary functions: they document past responses to the pandemic and, more importantly, they constitute ready-made operational tools to ensure business continuity in the face of future, unforeseen disruptions of a similar nature.

The purpose of the paper is to present the final results of the study, according to the impact of the organization of production processes on the scope of solutions implemented in Polish manufacturing companies.

In addition to the current section, the paper is structured as follows. Section “Materials and Methods” provides the research methodology. Section “Results” presents the results of the research, and in Section “Discussion” they are analyzed and discussed in detail. Section “Conclusion” summarizes the results obtained, highlighting the value of this research and the potential practical application for ensuring business continuity under a strict sanitary condition, caused by a pandemic or other factors.

Materials & Methods

The critical research problem was the identification, analysis, assessment, and recommendation of the scope of application of solutions aimed at ensuring business continuity during a pandemic implemented in manufacturing companies operating in various conditions. The following groups of protection measures implemented in manufacturing enterprises in response to the COVID-19 pandemic in manufacturing companies in Poland were identified from guidelines of international organizations ([IFMA, 2020](#); [ILO, 2020](#); [OSHA, 2020](#)), reports of consulting companies ([PARP, 2020](#); [PwC, 2020](#)), analysis of papers, and knowledge

of experts in the field of production management:

- (1) legal and regulatory measures
- (2) personal protective measures
- (3) protective measures for groups of workers
- (4) work organization measures
- (5) measures of production organization.

A survey using the multi-mode CAWI/CATI method carried out in 2021 on a representative sample of 600 manufacturing enterprises (random-variable sampling) obtained extensive diagnostic material on the extent of application of the various measures.

Comprehensive inclusion of research results was presented in the papers ([Kosieradzka et al. \(2022a, 2022b\)](#)). The research showed that solutions based on digital technologies (digital production documentation, remote work of supervisory personnel, automatic quality control, industrial robots, automatic transportation) are implemented at a relatively low level – the results were presented in [Kosieradzka et al. \(2023\)](#).

The research question addressed is related to measures to protect against the spread of the COVID-19 pandemic, but also other pandemics that may occur in the future, used in manufacturing companies. It is as follows. Do the measures used depend on the production type of the enterprise and the organization form of the production process?

In the following section of the article, the authors will study the impact of two types of production environments on the kind and scope of security measures. The first is the term “production type” understood as the diversity and repeatability of products manufactured in the enterprise:

- Unit production – manufacture of individualized products for customer orders (projects)
- Batch production – manufacture of a set of differentiated products in batches of tens to thousands of identical products
- Mass production – manufacture of a large number of identical products or their variants with a high degree of similarity

The second is the production organization form understood which depends on how materials flow between stations carrying out successive operations of the production process ([Margherita & Heikkilä, 2021](#)):

- Line production (product-oriented production) – a category of manufacturing processes, that arranges special-purpose machines and equipment in a rigid sequence to perform repetitive standard products for large orders.
- Job-shop production – a category of manufacturing processes that irregularly produces single or small lots in a shop characterized by flexible machines and skilled workers; occurs as a job shop with a process layout, and a job shop with the product layout.

Detailed characteristics of each of the production environments discussed are presented in Fig. 1.

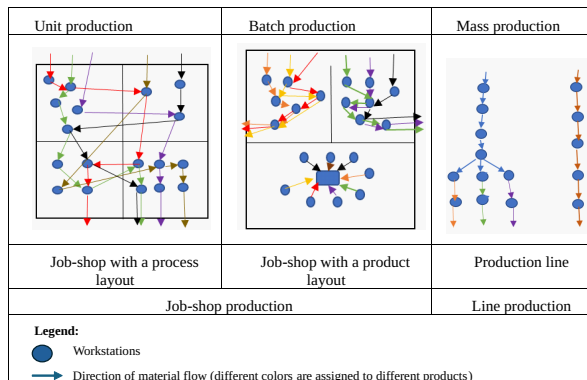


Fig. 1. Correlations between types of production and forms of production organization (source: own study)

The implementation of the production process, defined as the manner in which individual operations are allocated to workstations and the resources required to complete the assigned tasks depends on a variety of factors. One of these factors is the demand for the manufactured product, which determines the allocation by type of production. Depending on the size and stability of the demand, an enterprise will produce a small number (single pieces) of unique products for a particular customer order (unit production), passing through repetitive demand for products (batch production), and ending with the production of a large volume of standardized products according to a fixed range (mass production).

The manner in which production is organized varies depending on the type of production. In the unit type, an extensive range of operations are performed at different workstations (depending on the required technology) by workers with versatile skills. In the batch type, cells tend to have subject specialization (spaced according to the course of operations assigned to the product). Concurrently, employees are still regarded as having a comprehensive competence but may be at a lower level. In the mass type, on the other hand, operations are strictly assigned to specific production positions, and employees are characterized by very narrow but specialized competencies in a particular field.

Due to the wide variation in characteristics, different risks appear for each type of production concerning the five groups of measures studied. Legal considerations may be similar for every kind of production. However, personal protective measures and protective measures for groups of workers may already vary and depend on the repetitive nature of the operations performed (high repetitiveness affects the intensification of contacts, and therefore, a higher probability of infection) or the

importance of the resource to the organization (for example, the absence of employees with unique competencies may jeopardize the uninterrupted execution of the production process). Depending on the frequency with which the operations in question are performed, the organization may also be considering the use of more structured solutions, covering the entire organization due to their high efficiency or the ability to distribute the expenses incurred over the high number of products produced.

The second factor is the organization of workflow through individual workstations, which is related to the repetitive operations performed. Depending on the interconnection of workstations in the production process, it can be characterized by a lack of fixed allocation of operations to workstations (job-shop production) or fixed allocation of operations to workstations (line production). In the job-shop production, the key will be the optimal use of machinery and equipment and the qualifications possessed by employees (relatively high, given the high flexibility of assigned tasks). In the line production, on the other hand, activities focus on ensuring the efficient and effective flow of materials to make the finished product. At the same time, as in mass production, the requirements for employees are more specialized but at a lower level. The two forms of production organization represent contrasting approaches. Also of interest in the study was the effect of the implemented form of production organization on the range of security measures used, grouped into the five categories mentioned above. A more structured flow structure can influence the choice of solutions used due to facilitating the implementation of solutions and reduce operational costs (especially in the case of solutions for the enterprise's digitalization (measures of production organization). Irregular flow, on the other hand, may force a company to use unconventional measures because standard solutions are either impossible to implement or ineffective.

To determine whether the implementation of specific protection measures is significantly related to the production environment, Pearson's chi-square test for independence was employed. For each of the identified measures, the analysis tested the null hypothesis stating that the occurrence of a given measure is independent of the production type (unit, batch, or mass) and, respectively, the production form (line or job-shop). Rejection of the null hypothesis at a significance level indicated that the type or form of production organization significantly influences the adoption of a particular measure. This statistical verification allowed for identifying which specific solutions are characteristic of or determined by the technical and organizational conditions of the manufacturing process.

The research process completed by the authors consisted of four stages, as detailed in Fig. 2.

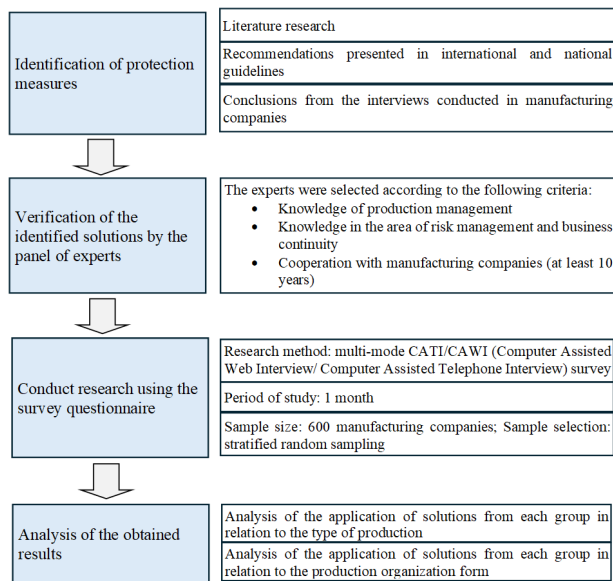


Fig. 2. The research methodology (source: own study)

As part of the conducted research, it was decided to analyze 42 solutions enterprises could apply at the operational level. The identification of potential measures was preceded by a literature analysis in the area of guidelines, requirements, and recommendations formulated for manufacturing enterprises regarding their ability to protect themselves against the adverse effects of the COVID-19 pandemic. The results obtained were superimposed on the results obtained from interviews and case studies conducted at selected manufacturing enterprises. The formulated measures were also reviewed by a panel of experts built for the ongoing IDUB against COVID-19 project granted by Warsaw University of Technology under the Excellence Initiative: Research University (IDUB) program. A list of identified safeguard measures is presented in Fig. 3.

Results

The objective of the study was to determine the relationship between the measures used and the kind of production carried out at the company. The production environment was defined as the type of production carried out (dependent on the size/number of products produced) and the form of production (dependent on the flow of materials/semi-finished products). The results were analyzed along these two dimensions. At a particular enterprise production is carried out in

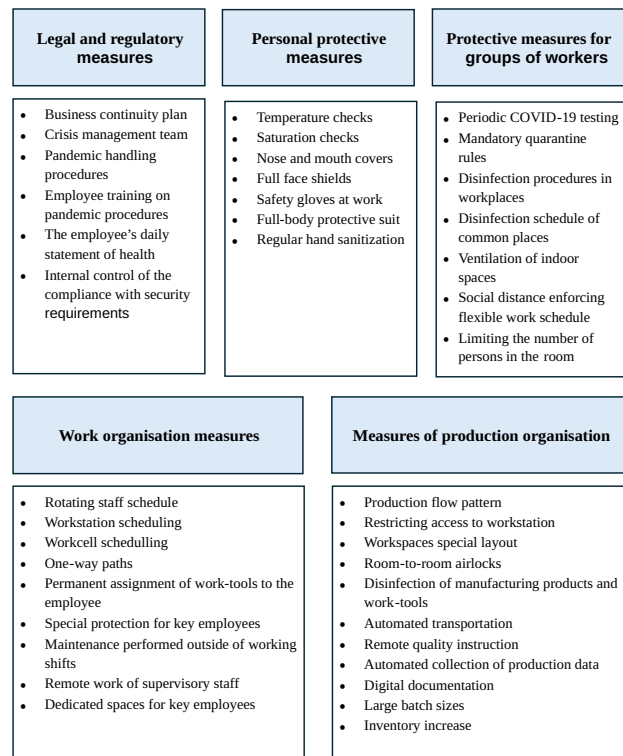


Fig. 3. The list of identified protection measures (source: own study)

different ways in different production areas. Within the framework of the gathered results, a single company had the opportunity to report the realization of one, two, or three types of production in parallel and one or two forms of production in parallel.

The use of measures in various types of production

The group of legal and regulatory measures was subjected to a comprehensive analysis, which encompassed six security solutions. The use of pandemic procedures was the most common among the surveyed companies. In contrast, the least frequent use was the employee's daily statements (for more than 80% of employees). It should be noted that in all types, the largest share of the use of a solution is in batch production. In most of the solutions used, the widespread use of measures (although less than in mass production) can be seen in the unit type. The results are presented in Fig. 4.

The chi-square test indicated that the production type has statistically significant effect ($p < 0.05$) on the probability of using two measures: the business continuity plan and the crisis management team. The results of chi-square test are presented in Tab. 1.

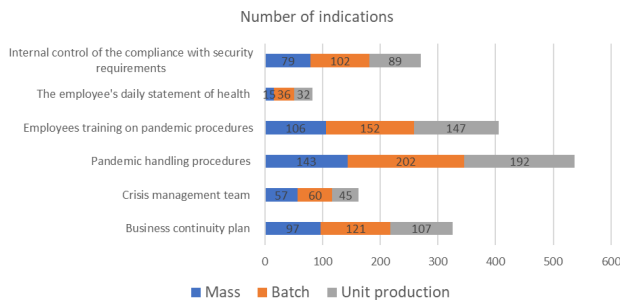


Fig. 4. The use of legal and regulatory measures in different production types (source: own study)

Table 1
 The results of the chi-square test for legal and regulatory measures according to production type

Legal and regulatory measures	χ^2
Business continuity plan	8.16
Crisis management team	13.17
Pandemic handling procedures	4.42
Employees training on pandemic procedures	1.25
The employee's daily statement of health	3.39
Internal control of the compliance with security requirements	5.36

(source: own study)

Within the group of personal protective measures, seven security solutions were analyzed. The most frequently used measure in any production type is the use of mouth and nose covers (for more than 80% of workers) – 398 indications. In contrast, the least frequently used solution is the saturation checks (for more than 80% of workers).

The results are presented in Fig. 5.

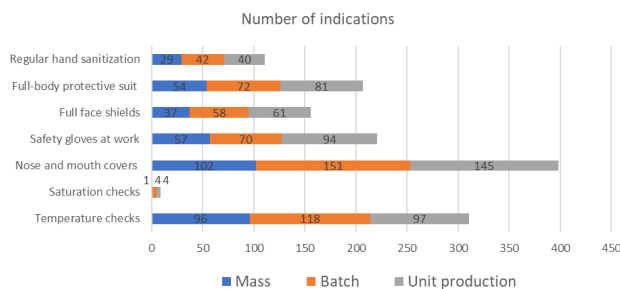


Fig. 5. The use of personal protective measures in different production types (source: own study)

Differences are observed in the application of individual measures across different production types, with three solutions being more frequently used in batch production and four solutions more prevalent in

mass production. However, the chi-square test results indicated that the production type has statistically significant effect ($p < 0.05$) on the probability of using only one of the measures in the studied group: temperature checks. The results of chi-square test are presented in Tab. 2.

Table 2

The results of the chi-square test for personal protective measures according to production type

Personal protective measures	χ^2
Temperature checks	12.75
Saturation checks	1.01
Nose and mouth covers	1.29
Safety gloves at work	3.42
Full face shields	0.38
Full-body protective suit	0.27
Regular hand sanitization	0.25

(source: own study)

Within the group of protective measures for groups of workers, seven security solutions were analyzed. The most frequently used solutions were disinfection procedures in workplaces (532 indications) and social distance enforcing (463 indications). Within four measures more frequent use was noted in batch production than in other types. Two measures were used slightly more often in unit production than in batch production. The application of mandatory quarantine rules was applied only in mass production (2 cases). The results are presented in Fig. 6.

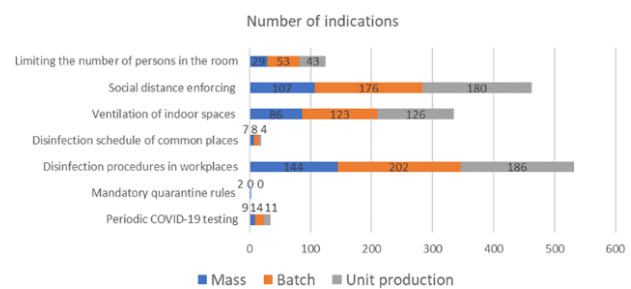


Fig. 6. The use of protective measures for groups of workers in different production types (source: own study)

The chi-square test results indicated that the production type has statistically significant effect ($p < 0.05$) on the probability of using only one measure within the investigated group – disinfection procedures in workplaces. The results of chi-square test are presented in Tab. 3.

Table 3

The results of the chi-square test for protective measures for group of workers according to production type

Protective measures for group of workers	χ^2
Periodic COVID-19 testing	0.56
Mandatory quarantine rules	5.82
Disinfection procedures in workplaces	7.65
Disinfection schedule of common places	2.63
Ventilation of indoor spaces	0.08
Social distance enforcing	4.19
Limiting the number of persons in the room	2.45

(source: own study)

Within the group of work organization measures, eight were analyzed. The most frequently used solutions were the use of dedicated spaces for key employees (320 indications) and the rotating staff schedule (281 indications). The least frequently used solutions in all types of production were the introduction of one-way paths (for more than 80% of routes) (14 indications) and the organization of supervisory staff remotely (for more than 80% of employees) (6 indications). The results are presented in Fig. 7.

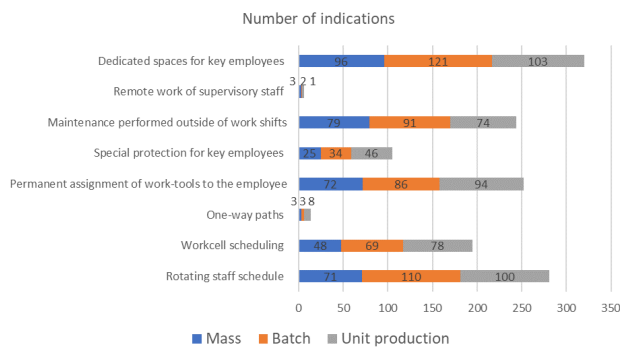


Fig. 7. The use of work organization measures in different production types (source: own study)

Differences are observed in the frequency of implementing individual measures across production types. Specifically, three solutions are more prevalent in batch production, while the remaining studied measures are more common in unit production. The results of the chi-square test demonstrate that the production type has a statistically significant effect ($p < 0.05$) on the probability of using two specific measures: maintenance performer outside of work shift and dedicated space for key employees. The results of chi-square test are presented in Tab. 4.

Within the group of production organization measures, twelve solutions were analyzed. The most fre-

Table 4

The results of the chi-square test for work organizations measures according to production type

Work organizations measures	χ^2
Rotating staff schedule	1.79
Workcell scheduling	0.47
One-way paths	1.51
Permanent assignment of work-tools to the employee	1.82
Special protection for key employees	1.68
Maintenance performed outside of work shifts	11.58
Remote work of supervisory staff	2.08
Dedicated spaces for key employees	9.6457

(source: own study)

quently used solutions were the production flow pattern with the use of 1.5 distances between workstations (663 indications), disinfection of products and work-tools (359 indications) indications, and the replacement of hard copy documentation with digital ones (357 indications). The least frequently used solution was the use of airlocks between production areas (56 indications). The results are presented in Fig. 8.

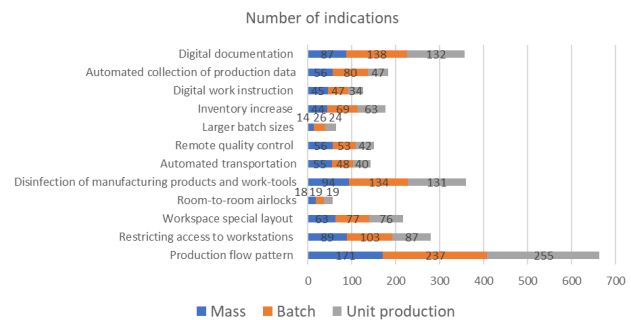


Fig. 8. The use of measures of production organization in different production types (source: own study)

Differences are observed in the implementation frequency of individual measures across production types, with a substantial majority of the identified measures being used more frequently in batch production or at levels similar to unit production. The results of the chi-square test demonstrate that the production type has a statistically significant effect ($p < 0.05$) on the probability of using five specific measures from the studied group. The more frequent application of restricting access to workstations (glass/plexiglass walls) and digital work instructions in batch production is statistically significant and constitutes a key finding of this study. Furthermore, it was observed that two

solutions: automated transportation and remote quality control were used significantly more frequently in mass production, with the chi-square test confirming that these dependencies are also statistically significant. The results of chi-square test are presented in Tab. 5.

Table 5

The results of the chi-square test for measures of production organization according to production type

Measures of production organization	χ^2
Production flow pattern	0.63
Restricting access to workstations	12.44
Workspace special layout	2.19
Room-to-room airlocks	1.37
Disinfection of manufacturing products and work-tools	0.77
Automated transportation	16.45
Remote quality control	15.00
Larger batch sizes	0.76
Inventory increase	0.91
Digital work instruction	10.97
Automated collection of production data	15.84
Digital documentation	1.73

(source: own study)

The use of measures in various of production organization forms

Within the group of legal and regulatory measures, six solutions were analyzed. The results indicate that in job-shop production pandemic handling procedures are used significantly more often. In contrast, two solutions, such as drawing up business continuity plans and establishing a crisis management team, are more commonly used in line production. The results are presented in Fig. 9. The chi-square test of independence confirmed the results described previously. The statistical analysis demonstrates that the production form has a statistically significant effect ($p < 0.05$) on the probability of implementing four specific solutions: business continuity plan, crisis management team, pandemic handling procedures, and internal control of compliance with security requirements. The results of chi-square test are presented in Tab. 6.

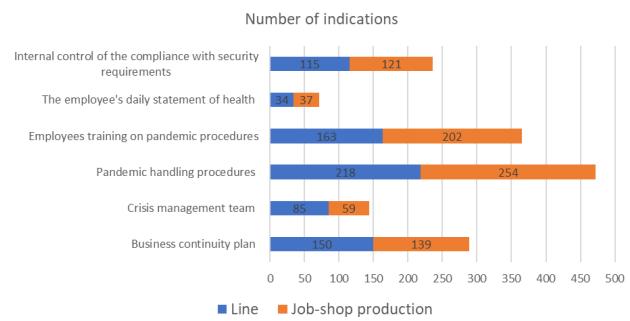


Fig. 9. The use of legal and regulatory measures in various forms of production organization (source: own study)

Table 6

The results of the chi-square test for legal and regulatory measures according to production organization forms

Legal and regulatory measures	χ^2
Business continuity plan	20.23
Crisis management team	21.74
Pandemic handling procedures	11.08
Employees training on pandemic procedures	2.29
The employee's daily statement of health	1.13
Internal control of the compliance with security requirements	6.72

(source: own study)

Within the group of personal protective measures, seven solutions were analyzed. Four solutions are more common in job-shop production. In contrast, full face shields (for more than 80% of workers) are more common in line production. The saturation checks occurred at a very low level in both production organization forms. The results are presented in Fig. 10.

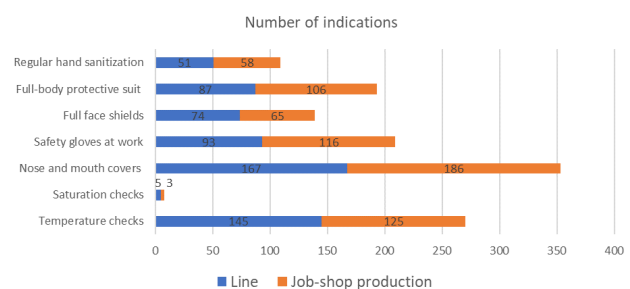


Fig. 10. The use of personal protective measures in various forms of production organization forms (source: own study)

The results of the chi-square test demonstrate that the production form has a statistically significant effect ($p < 0.05$) on the probability of implementing three specific measures: temperature checks, full face shields, and nose and mouth covers. The results of chi-square test are presented in Tab. 7.

Table 7

The results of the chi-square test for personal protective measures according to production organization forms

Personal protective measures	χ^2
Temperature checks	25.17
Saturation checks	1.40
Nose and mouth covers	8.49
Safety gloves at work	0.77
Full face shields	8.53
Full-body protective suit	1.05
Regular hand sanitization	1.22

(source: own study)

Within the group of protective measures for groups of workers, seven measures were analyzed. The vast majority of solutions are much more frequently applied in job-shop production than in line production. Three solutions, such as periodic COVID-19 testing, performing of common places disinfection every 2 hours, and mandatory quarantine rules were very rarely implemented in each form of production. The results are presented in Fig. 11.

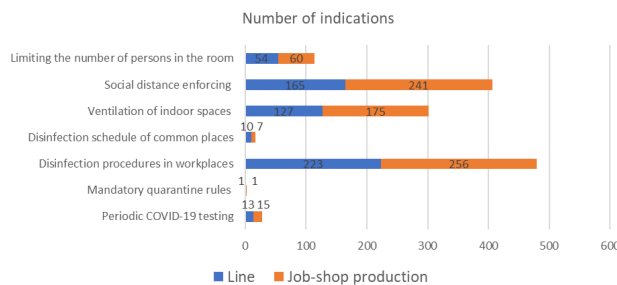


Fig. 11. The use of protective measures for groups of workers in various of production organization forms (source: own study)

The results of the chi-square test demonstrate that the production form has a statistically significant effect ($p < 0.05$) on the implementation of a single measure: disinfection procedures in workplaces. This statistical outcome confirms a significantly higher frequency of using this solution in job-shop production compared to line production. The results of chi-square test are presented in Tab. 8.

Within the group of work organization measures, eight solutions were analyzed. The vast majority of solutions are much more frequently applied in job-shop production than in line production. The results are presented in Fig. 12.

Table 8

The results of the chi-square test for protective measures for group of workers according to production organization forms

Protective measures for group of workers	χ^2
Periodic COVID-19 testing	0.23
Mandatory quarantine rules	0.05
Disinfection procedures in workplaces	13.77
Disinfection schedule of common places	2.03
Ventilation of indoor spaces	0.00
Social distance enforcing	0.76
Limiting the number of persons in the room	1.62

(source: own study)

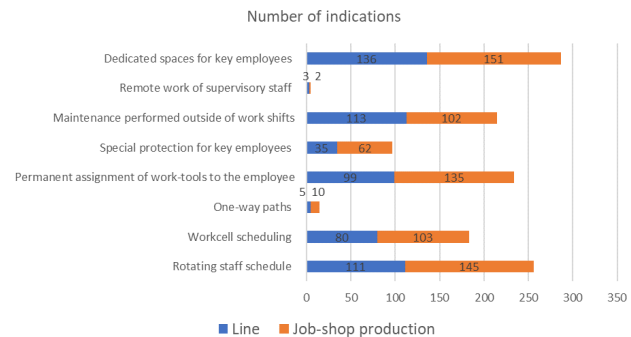


Fig. 12. The use of work organization measures in various of production organization forms (source: own study)

The results of the chi-square test demonstrate that the production form has a statistically significant effect ($p < 0.05$) on the probability of implementing two specific measures: maintenance performed outside of work shifts and dedicated spaces for key employees. The results of chi-square test are presented in Tab. 9.

Table 9

The results of the chi-square test for work organizations measures according to production organization forms

Work organizations measures	χ^2
Rotating staff schedule	0.22
Workcell scheduling	0.20
One-way paths	0.47
Permanent assignment of work-tools to the employee	0.01
Special protection for key employees	1.85
Maintenance performed outside of work shifts	15.10
Remote work of supervisory staff	0.67
Dedicated spaces for key employees	5.92

(source: own study)

Within the group of production organization measures, eleven solutions were analyzed. The obtained results indicate a diversified application of the specific measures depending on the production form. None of the analyzed measures, however, were implemented exclusively within a single production organization form. In contrast, two specific solutions were found to be significantly more prevalent in line production. These include automated transportation, and remote quality control. The results are presented in Fig. 13.

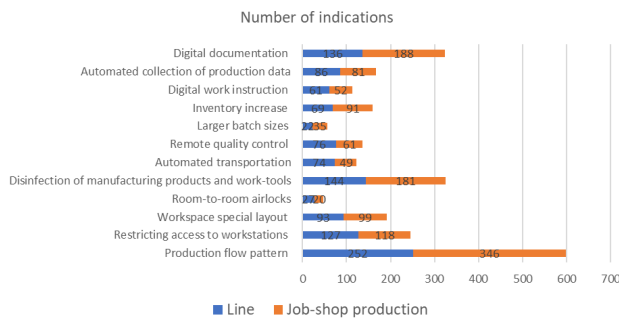


Fig. 13. The use of measures of production organization in various of production organization forms (source: own study)

The results of the chi-square test demonstrate that the production form has a statistically significant effect ($p < 0.05$) on the probability of implementing seven specific measures. A substantial majority of these identified measures are significantly more prevalent in line production. An exception is workspace special layout, which shows a significantly higher implementation rate in job-shop production. The results of chi-square test are presented in Tab. 10.

Table 10

The results of the chi-square test for measures of production organization according to production organization forms

Measures of production organization	χ^2
Production flow pattern	0.04
Restricting access to workstations	15.21
Workspace special layout	4.55
Room-to-room airlocks	4.95
Disinfection of manufacturing products and work-tools	1.36
Automated transportation	20.34
Remote quality control	12.79
Larger batch sizes	0.30
Inventory increase	0.11
Digital work instruction	7.99
Automated collection of production data	8.20
Digital documentation	0.00

(source: own study)

Discussion

In the majority of the studied groups of measures, the widest application of solutions (measured by the number of indications) occurs in batch production. This dependence is particularly evident in the group of formal and legal measures and measures of production organization. Batch production follows a fixed schedule, repeatable in selected periods, which affects the ease of implementing certain solutions. For instance, the implementation of procedures pertaining to the limitation of the spread of pandemics or the implementation of training in the knowledge of procedures is more straightforward in orderly organizational structures. A certain repetitiveness of batch production (its compliance with the schedule) also makes it possible to apply work organization solutions, such as maintenance on non-production shifts. The implementation of those solutions requires adherence to and compliance with established work schedules. Conversely, in the group of production organization measures, the relatively fixed assignment of tasks (variable within individual products, but fixed in the course of a given series) increases the benefits of introducing digital work instructions or automated collection of production data. The measures taken to implement these solutions are not affected by the production of a series of products, rather than individual products as in the case of unit production.

A balanced distribution of measures used in batch production and unit production is observed in two groups: individual protection measures and protective measures for groups of workers. The extent of implementation is similar probably because some of these measures are among the key recommendations made by either state administrative authorities or international health institutions (IFMA, 2020; ILO, 2020; OSHA, 2020).

In selected groups, such as legal and regulatory measures, work organization measures, and measures of production organization, certain solutions are much more frequently used in mass production than the other types. In legal and regulatory measures, an example of such a solution is the establishment of a crisis management team, while mass production with the assignment of specific tasks to a specific employee or a formalized structure allows the use of the relevant competencies of team members and facilitates the management of such a team (MSA/MC/GSC, 2020).

In the group of measures of production organization, on the other hand, some of the solutions are easier to adapt in mass production, for example, automatic transportation or remote quality control. The research

results are presented in an article on the use of digitization to support business continuity activities in the COVID-19 pandemic (Kosieradzka et al., 2023). This is due to the possibility of spreading the high cost of investment over a larger number of manufactured products. Also noteworthy is the fact that in the group of protective measures for groups of workers, the introduction of the principles of quarantine organization and the method of its shortening occurs only in enterprises implementing mass production, in other types it has not been introduced. Indicated dependencies were mentioned in the PwC report compiled at the pandemic's beginning (PwC, 2020).

In unit production, too, one can note the significant use of selected solutions. For example, it is in this type of production that it was decided to protect employees with key competencies. Knowing that the knowledge and experience of these people are invaluable in the manufacture of new, previously unmanufactured products. The significant role of ensuring staffing for critical workstations requiring specialized knowledge was included in the recommendations of state institutions (MSA/MC/GSC, 2020).

Research conducted using the chi-square test demonstrates that the production type has a statistically significant effect ($p < 0.05$) on the likelihood of implementation of eleven specific measures. However, the detailed relationships governing the use of these measures, as well as the environmental factors favoring their application relative to the characteristics of each production type, should be the subject of further research. The results obtained indicate a wide variation in the degree of application of individual measures in different forms of production organization. Line production, due to the repetitive flow of materials/semi-finished products and the assignment of given operations to specific workstations, is characterized by a high degree of orderliness. In such production, it is easier to introduce solutions both in terms of formal and legal measures (development of business continuity plans), individual protection of employees (temperature checks or full face shields), as well as solutions in terms of production organization. The repetition of tasks performed and the assignment of these tasks to specific workstations makes it possible to schedule maintenance in non-production shifts. That is known at what hours/times of the day work is performed at each workstation.

Some of the measures, as in mass production, are more cost-effective to implement in line production. In the case of automated transportation, to implement optimization of transport routes and at the same time ensure the profitability of invested resources, it is crucial to provide fixed transport routes (rarely

changing). In job-shop production, where the flow of materials/semi-finished products is variable, such solutions are often subject to modification and can prove to be financially inefficient. This issue was studied as part of the work carried out by IDUB against the COVID-19 project granted by the Warsaw University of Technology under the Excellence Initiative program (Kosieradzka et al., 2023).

Within the surveyed group, enterprises characterized by job-shop production devoted considerable attention to both individual and collective protective equipment. Although these observations did not reach statistical significance, a high frequency of implementation was noted for measures such as mouth and nose covers, gloves, and full protective suits. This descriptive trend may be attributed to the typically higher mobility of workers in job-shop environments compared to line production. Similarly, collective measures, including continuous air filtration and systematic disinfection, were frequently reported, potentially serving as a redundant safety layer. Furthermore, it is noteworthy that a considerable number of these enterprises indicated a permanent assignment of work-tools to employees. While this solution is traditionally associated with the workstation-specific nature of line production, its presence in the surveyed job-shop enterprises suggests an effort to minimize tool-sharing as a precautionary measure. Not all of the aforementioned measures were found to be statistically significant in the chi-square test. Therefore, their implementation should be the subject of further research.

The presented study can be one of the solutions to prevent the spread of infections. The permanent assignment of work-tools to workers minimizes the need to exchange tools between workers, and thus the possibility of virus transmission. Job-shop production is characterized by variability in the flow of materials/semi-finished products during the implementation of the production process. It affects the increased benefit of implementing selected measures, especially from the group of production organization measures. High turnover of the type of manufactured products affects the need for disinfection of products and work-tools, as well as the convenience of replacing hard copy documentation with digital ones. It is inefficient to print new documents (information on design, manufacturing technology) with each change in the tasks performed.

The study revealed a high reproducibility measures in line and mass production, and similarly for job-shop production and unit production. The analogies are due to the similar characteristics of the production environments studied. The results obtained from the study also indicated significantly more varied results of applying specific security measures in different forms

of production organization, more so than in types of production. This phenomenon is probably related to the fact that the type of production is closely related to the demand for a given product and the adaptation of the production organization under the number of products produced, considering their differentiation. The production organization form, on the other hand, is closely related to the assumed flow of materials/semi-finished products, and it is how the various operations are carried out and the relationships that exist between them that have the most significant impact on the applicability of measures and their anticipated effectiveness.

Referring to the research Margherita & Heikkilä (2021) the results presented in the paper discussed the measures used at the operational level in the areas and sub-areas: (1) Operation and Value System (Supply Chain Status, Logistic Flow In/Out, Manufacturing Processes) and (3) Workforce and Human Capital (Prevention Measures, Job Continuity/Productivity, Handling of Cases).

Given the constant reports of new mutations of the COVID virus, admittedly at a much lower risk to the public but cyclically occurring, the results obtained from the study are applicable even several years after a pandemic. The recommendations presented here are relevant both in the situation of the next pandemic – the occurrence of which within several years have been warned about by many health institutions in recent years (OECD, 2023; Williams et al., 2023) – as well as in the situation of standard periods of illness of some of the company's employees, for example, during the autumn and winter periods or increased incidence of influenza. It is worth remembering that the recommendations developed also apply to disease phenomena with lesser effects than those initially caused by the COVID-19 pandemic, minimizing the impact of increased public morbidity of a particular disease entity on the ability to carry out production processes in the enterprise. Such measures increase the organization's resilience to the disruptions that occur or enable it to maintain business continuity with regard to the production processes being carried out.

Conclusions

The paper presents the analysis of pandemic protection measures for different types and forms of production organizations. The measures used by manufacturing enterprises were collected, organized and analyzed. The findings may support business continuity of these enterprises, taking into account the specific characteris-

tics of production organizations. They can also be used in other organizations that operate on principles similar to the enterprises for those described in the paper.

The results of the research can be applied directly by managers of enterprises. Of particular interest to them may be the comparison of measures used in different types and forms of production organization. As shown, the vast majority of solutions are more often used in batch production than in other types of production. Selected solutions are used both in the line production form and in mass production, particularly in the group of production organization measures. This is due to the characteristics of both manufacturing environments. Furthermore, the similarity was also observed between the results obtained in the unit production and job-shop production, particularly in the group of work organization measures.

These general conclusions, as well as specific results, could prove invaluable in the event of the recurrence of risks similar to those discussed. If the pandemic threat persists, in-depth studies should focus on the groups where large variations in the level of measures were observed. This may facilitate the identification of the most effective measures for different production enterprises and organizations.

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