Sustainability Efforts in Practice in European Hotels: A Tricky Business?

DOI: 10.12776/QIP.V26I3.1773

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Received: 2022-10-17 Accepted: 2022-10-28 Published: 2022-11-30

ABSTRACT

Purpose: This article investigates some tendencies around sustainability work in practice performed during the past five years.

Methodology/Approach: Interviews with hotel managers and staff members, observations on the hotels were conducted. Secondary data material (home pages, guest reviews via websites) has been investigated as document studies.

Findings: The two waves of the pandemic 2020 and 2021 have, on the one hand, offered time for hotel leaders to rethink knowledge about sustainability in their businesses and, on the other hand, taken the focus from sustainability to matters of survival, both physically and economically. Despite financial support from the state for staff retention, many accommodating organisers today are struggling with a staff shortage. The study shows that a few accommodation entrepreneurs have invested wholeheartedly in sustainability measures during the last five years despite the increased social debate about the importance of more sustainable living. The results show some tendencies regarding the practical work for sustainability. Sustainability work has not achieved the desired results in practice due to, among other things, a lack of knowledge, so-called green-washing, disengagement, lack of personnel, financial losses due to pandemics etc.

Research Limitation/Implication: The study makes no claim to statistical representativeness either in the choice of the hotels, their size, geographical location or in any other respect.

Originality/Value of paper: The study consists of 51 interviews of hotel managers performed in 11 European countries.

Category: Research paper

Keywords: hotel; manager; sustainability; practice; understanding the assignment

1 INTRODUCTION

1.1 Background

As sustainability demands in our societies are increasing, it arouses curiosity about the effect of its implementation and positioning in the business, not at least within the tourist industry. The tourist industry has been having significant impacts on the global economy. Each year before the pandemic, the number of tourist arrival increased widely and is still slowly doing so in the post-pandemic era. Based on the World Travel and Tourism Council (WTTC), there was a 3.5% growth for the tourism industry in 2019, bringing a contribution of US$ 8.9 trillion to the world's GDP (WTTC, 2019). In the tourism industry, hospitality was valued at $7.17 trillion in 2016 (WTTC, 2016). The pandemic and several lockdowns have changed the picture, however. During the pandemic, most European countries offered governmental support for the survival of tourist organizations that suffered the loss of customers. This support abled them to keep their staff.

In July 2022, international tourism continued to show vital signs of recovery, with arrivals reaching 57% of pre-pandemic levels in the first seven months of 2022. The steady recovery reflects strong demand for international travel and the easing or lifting of travel restrictions (86 countries had no COVID-19-related restrictions as of 19 September 2022) (UNWTO, 2022). Now it is also the time to rethink tourism, where it is going and how it impacts people and the planet, noticed by UNWTO Secretary-General Zurab Pololikashvili. Europe and the Middle East showed the fastest recovery in January-July 2022, with arrivals reaching 74% and 76% in 2019, respectively. Europe welcomed almost three times as many international arrivals as in the first seven months of 2021 (+190%), boosted by strong intra-regional demand and travel from the United States (UNWTO, 2022). These demands have also created significant operational and workforce challenges in tourism companies and infrastructure, particularly airports, restaurants and hotels. Additionally, the economic situation, exacerbated by the aggression of the Russian Federation against Ukraine, represents a major downside risk. The combination of increasing interest rates in all major economies, rising energy and food prices and the growth prospects of a global recession, as has been indicated by the World Bank, are major threats to the recovery of international tourism through the remainder of 2022 and 2023. The potential slowdown can be seen in the latest UNWTO (2022), which reflects a more cautious outlook and in booking trends showing signs of slower growth (World Bank, 2022; UNWTO, 2022).

One way of working on sustainability in practice at hotels has been Green certification approaches. Since ISO 14001 in 1996 (Boiral et al., 2018), there has been steady growth in certified organizations and the recent trend of decertification (Mosgaard and Kristensen, 2020). In the literature review, Boiral et al. (2018) found that studies tend to focus on the impact of ISO 14001 on

management practices, environmental indicators, environmental awareness and company image. The focus lies on effectiveness and positive aspects (76%) (Erauskin-Tolosa et al., 2019). Boiral et al. (2018) argue that this conceals potential undesirable effects such as bureaucracy, organizational resistance, cost of implementation, lack of resources and commitment from managers (Boiral et al., 2018). Several recent studies question the overall impact of environmental certification schemes: symbolic adoption of schemes, the impact on environmental performance and integration into the organizational climate (e.g. Boiral et al., 2018; Heras-Saizarbitoria, Boiral and de Junguitu, 2020; Testa, Boiral and Iraldo, 2015). Other studies indicate that there may be problematic issues relating to certifications (e.g. Valenciano-Salazar et al., 2021).

Green certifications are a third-party organization's acknowledgement that a hotel abides by a set of environmental standards and continually strives to have a positive environmental impact. Green certifications are developed by private and public agencies worldwide. LEED, Green Seal, and Green Key are some of the most recognized green certifications for hotels. Many hotels hope these certifications will attract more customers, leading to higher hotel bookings, room prices, and revenues. However, several studies have not been able to confirm this connection. Many more and different parameters influence customers' choice of accommodation (Chong and Verma, 2013; Walsman, Verma and Muthulingam, 2014). Studies also investigate why hotels do not prioritize investing in green labels. Environmental protection is not the primary consideration of consumers seeking accommodations. Lack of support by investment owners (shareholders) and lack of relevant subsidy incentives are often mentioned as reasons. In the hotel and tourism field, though, consumers' understanding of the sustainable development of hotels is also increasing (Verma and Chandra, 2018).

Since the hospitality industry includes so many different areas, this study focuses on the accommodation industry in European countries seen through interviews with 51 hotel managers in 11 countries. Through these impacts, it is interesting to learn profoundly about the sustainable perspectives of business owners, managers and the staff. As a result, this perspective leads to some research questions; How do the managers understand the demands on sustainability in their businesses? How do they feel about implementing sustainability issues? What is the driving force in practical work towards more sustainable accommodation businesses? This article investigates some tendencies around sustainability work in practice performed during the past five years in hotel accommodations in several European countries.

2 THE THEORETICAL PERSPECTIVES

2.1 Understanding the Assignment and Understanding Responsibilities towards Sustainable Practice

Sustainable world?

During the last decades, have undoubtedly environmental problems, e.g. pollution, deforestation and desertification, become real to us all. The environmental threats are consequences of the exploitation of Nature.

Those threats, together with structural changes in manufacturing and production of goods and services, i.e. how we live and consume, show that we still have huge environmental challenges ahead of us (Hahn et al., 2014; Gullikson and Holmgren, 2015; Thurén, 2015). Sustainability is a well-used term, appearing almost daily in the media and increasingly in everyday conversation, often described as something good to strive for. Moving towards a more sustainable way of living will inevitably require radical changes in attitudes, values and behaviours (Hahn et al., 2014; Gullikson and Holmgren, 2015).

Corporate social responsibility (CSR) has become an established part of business practice in recent times. It is expressed that improved regulations, benefits as increased market shares, enhanced brand reputation, better employee retention rates, etc. are all attracting companies to CSR (Abaeian, Yeoh and Khong, 2014). Hotel business is strongly linked to the surrounding environment and the society in which they operate. The growth of the hotel industry can benefit local communities (Serra-Cantallops et al., 2017). This ables positive attitudes and can help to minimize harmful impacts on the environment and society. The ultimate goal for a business should be sustainability even though it is often interpreted as long-term profitability (Van Marrewijk, 2003).

Moreover, perhaps the best way to strive for sustainability is through organizational change initiatives (Appelbaum et al., 2016a). There have been discussions about the definition of sustainable development (Rambaud and Richard, 2015; Appelbaum et al., 2016a; Oxenswärdh, 2017), about how to interpret the concept in organizations and companies (Hahn et al., 2014; Appelbaum et al., 2016b; Oxenswärdh, 2018, 2020). Also research about how companies can create measures to get facts for decisions has been conducted. For instance, the Triple-Bottom-Line (TBL), created by Elkington in the 1990s, is nowadays a well-known concept that many organizations use (Slaper and Hall, 2011).

According to Naess (1995), the essential ideas informing an environmental worldview can be broadly shared without prescribing or predetermining ultimate premises or specific interpretations and actions. We need plural interpretations and actions appropriate to local cultures and conditions – echoing the ecological principle of diversity in unity. Paradoxically a sustainable worldview yields many different views of the same thing. The result of the Brundtland

Commission created challenges for countries and corporations. Corporate managers and other leaders in organizations have to make decisions in their companies and organizations with economic, environmental and social considerations, which is to some extent paradoxical and complex (Hahn et al., 2014).

Sustainability is a normative concept referring to an ideal state of being in which humans can flourish within the ecological thresholds of the planet alongside other living entities for perpetuity (Rockström et al., 2009).

Sustainability is not an end state that can be achieved but a moving target continuously changing and improving (Gaziulusoy, Boyle and McDowall, 2013). This dynamic state exists within thresholds, defined by the planetary boundaries framework, or the safe operating space for humanity (Rockström et al., 2009; Steffen et al., 2015). Seen from a systems perspective, sustainability is the ability of systems to persist, adapt, transform or transition in the face of constantly changing conditions.

2.2 Understanding the Assignment and Responsibilities

Responsibility is a word and a concept that is increasingly being mentioned in our society, not least when we are talking about matters of sustainability. It is pointed out how important it is, in any organizational context, to develop co-workers into responsible actors. In the scientific sense, the concept of responsibility is, first and foremost, a philosophical question. Philosophy and responsibility are interconnected on the one hand in the general question of what responsibility possibly is and on the other side of the normative question: what responsibility should be? (Kernell, 2002)

There is a certain dynamic between individuals, groups and organizations. Responsibility in any organizational context can be described as a relationship between the commissioner and the actor. Relations of responsibility constitute the arena where both the exaction and the assumption of responsibility can occur. Responsibility/accountability is a crucial question in all organizations working towards sustainability. Issues of accountability consequently have a direct relationship with professional development in organizations. An essential part of the organization's assignment is to assume responsibility. Different actors can understand both the assignment and the responsibility in different ways. This can be described in terms of the understanding of assignment and responsibility. The actors' understanding and interpretation of the assignment are significant for how they assume responsibility for fulfilling what they are commissioned to do. The understanding includes the cognitive and psychological processes and shows how the assumption of responsibility can be shaped (Abrahamsson and Andersen, 2005; Oxenswärdh, 2011).

When the understanding of responsibility describes what happens to the professionals and leads to heightened competence, the concept of responsibility can also be viewed as a pedagogical concept. The understanding of assignment

and responsibility can thus be regarded as a learning process, which is essential for the active assumption of responsibility. This learning process is integral to the organization staff's competence and professional development. These understanding processes can be seen as part of the collective learning process (Oxenswärdh, 2011, 2018). The process of understanding one's responsibility is, however, a more unexplored concept – unlike understanding the mission – and it has to do with the operator's approach in question the nature of the professional obligation to consider themselves obliged on assignment.

To illustrate the difference between the terms, it would be quite possible to find cases where assignments understanding of a co-worker is high, i.e. it is a clear picture of the tasks they believe the decision maker expects to be implemented. Despite this understanding, responsibility taking can be low, i.e. a number of different – e.g. moral/ethical/cultural – causes may hamper the actor's accountability to carry out the assignment. One way to express the distinction between mission understanding and the responsibility of understanding is to assume that the former rests on the legal and the latter on legitimate grounds. Concepts of legality and legitimacy disclose relations between justice and morality. Legality focuses on social actions in a formal sense and is sanctioned by the state or corporations, e.g. by orders and rules of law. Legitimacy is the more unspoken value system that has nothing to do with the formal legal system but rests on ethical foundations (Oxenswärdh, 2011, 2018). At the mission's core, understanding exists, seemingly even understanding responsibility. Responsibility understanding is formed at the core of an actor's competencies. Thus, it is further emphasized that actors' responsibilities also include understanding the approach to change and development. Change towards more sustainable practice needs both perspectives in the organizational context.

2.3 Co-creation of Values

Sustainability can be seen as a value we co-create in groups and teams. The creation or co-creation of values are two concepts often used in business and management literature and research. Today's consumers can be regarded as co-producers, creating meaning for the products, and at the same time, their consumption can be seen as an identification marker. Furthermore, this process adds sense to the development and makes the active customers participants in the product experience. This, again, transforms consumers into co-creators of values. (Bergman and Klefsjö, 2020). The relationship between the customer and the product provider can also be transferred to describe the relationship between several entrepreneurs and stakeholders working in groups or networking with each other or other actors. In this relationship, the project owner, the entrepreneur, invites partners into the learning process, offering them real-life challenges and continuously following up on the process (Oxenswärdh, 2018, 2020).

Co-creation of values emerges in practice, including processes of both individual and collective art. Both meaning-making and sense-making are seen as processes involved within the interaction between members of the team/group. Psychology describes meaning-making as a process through which people construe, understand, or make sense of life events, relationships, and themselves (Ignelzi, 2000). The method of meaning-making helps retain, reaffirm, revise or replace elements of a person's orienting system towards more nuanced, complex, and valuable (e.g., Gillies, Neimeyer, and Milman, 2014; Gadenne et al., 2012). The term is widely used in constructivist approaches and educational psychology (Ignelzi, 2000; Mortimer and Scott, 2003).

One way to create value between two different parties, e.g. entrepreneurs and their customers and stakeholders, is to pursue sustainability in practice. Value creation can lead to more viable tourism practices, thus contributing to a sustainable society. This does not happen without participation in collective and collaborative learning, meaning and sense-making, and knowledge sharing, where learning can occur.

These processes can be considered a framework for understanding the complexity of innovative problem-solving in sustainability issues in any group context. It is also assumed, in this article, that the creation of the values is a learning journey. To implement values in an organisation, it is necessary to tag on to collaborative culture. The design of collaborative culture requires creative thinking in solving problems, leadership, knowledge management, experiential learning, communication, quality management, and continuous improvement in an organisation (Roser, DeFillippi and Samson, 2013).

2.4 Managers and Management for Sustainability

For organisations to attain sustainable development and adapt to planned and unplanned changes, they primarily depend upon the competencies of their leaders and the collective competence of members. Research suggests sustainability leadership capabilities and a holistic perspective on the complexities of embedded organisations (Lozano, 2012; Metcalf and Benn, 2013). Maintaining a holistic perspective requires managing large amounts of complex information. (Metcalf and Benn, 2013). Several systems have been designed to monitor different organisational processes by incorporating sustainability at the strategic level. In management control research, a consensus has emerged over a long time on the importance of applying a holistic perspective, especially regarding how management control contributes to the realisation and development of organisations' strategies and goals. This holistic perspective has been labelled Management Control System (MCS). With the emphasis on systems, proponents of this approach argue that one should not study management control by focusing only on individual parts, such as e.g. a budget process. Instead, one should consider its various parts, financial as well as non-financial, that together constitute a control system (Nilsson and Olve, 2022). MCS are to contribute to

the development of an organisation, the various components of it should harmonise with each other. In research on management control and sustainable development, various theoretical concepts are used as the basis for analysis. For example, MCS as a package (Lueg and Radlach, 2016), sustainability control systems (Gond et al., 2012), environmental management control systems (Guenther, Endrikat and Guenther, 2016), environmental management accounting (Burrit and Schaltegger, 2010) and levers of eco-controls (Journeault, De Rongé and Henri, 2016). It is advocated (e.g. Gond et al., 2012; Lueg and Radlach, 2016) that there is a need to strengthen the link from management control theory into practice if sustainability is to be integrated into existing MCS. Otherwise, there is a risk that Sustainability Control Systems (SCS) and MCS exist parallel and with little influence on an organisation's sustainability strategies.

On the other hand, if used appropriately, MCS may push organisations toward sustainability (Guenther, Endrikat and Guenther, 2016). Leaders must maintain a long-term focus (Boiral et al., 2018) by incorporating different viewpoints and allowing decentralised decision-making in their operations (Wong, Ormiston and Tetlock, 2011). Leaders in organisations are considered to be the most crucial change agents responsible for bringing constructive changes in working toward sustainability. Further on, leaders must be proactive in bridging the gaps between implementing various strategic decisions, management roles, and organisational changes. Leaders must have competence and knowledge endowed with vision and innovative approaches to guide, encourage, motivate, counsel, appraise, and reward employees to fulfil the needed change processes. Furthermore, sustainable development embraces business, economic, environmental, and social dimensions (Gladwin, Kennelly and Shelomith Kause, 1995). Competent and effective leadership is essential to achieve sustainable development in the context of complex and challenging adaptive changes. Preparation for future contingencies is the primary job of leaders. They have to provide clear directions and lead the team so they can win their team's support to achieve the organisation's common goals. They also have to bring technological and adaptive changes to the organisation for sustainability. Furthermore, and not least, because sustainability can be seen as a value, ethical competence by leaders is of crucial importance (Ferdig, 2007). Management scholars have recognised that the complexity of highly interdependent systems necessitates a systems approach, viewing social systems nested within natural systems (Gladwin, Kennelly and Shelomith Kause, 1995).

To summarise the section above, it can be stated that there are different processes within a learning journey for organizations to adopt more sustainable practices. There is a need for knowledge sharing over the facts on sustainability issues throughout the organization. Processes of understanding sustainability demand as an assignment and understanding the responsibilities within are essential in organizations in starting the work towards more sustainable practice. Furthermore, the process of co-creation of values must not stand only inside and

among own organization as an internal concern but also include all stakeholders. To lead these processes, there is a need for leadership with a strong commitment to change management. Knowledge of these processes is of immense importance in any organization to avoid the so-called window-dressing function or to greenwash sustainability issues.

3 METHODOLOGY

This study has a qualitative and an exploratory approach with thematic content analysis as a method. The study aimed to capture insights into the practical sustainability work within the accommodation business. The data collection consists of 51 one-hour interviews with hotel managers in 11 European countries. Also, some staff members were spontaneously interviewed shortly at the locations. Furthermore, observations were conducted during the visits. The study does not claim statistical representativeness of the hotels' sustainability work in general but instead describes some tendencies in work towards sustainability in randomly selected hotels.

Data collection took place between March and May 2022. Countries in which the survey was conducted were: Germany, Holland, Belgium, France, Italy, Greece, Bulgaria, Romania, Hungary, Slovakia and Poland. The selected hotels in these countries differed in number, size, organizational form and geographical location. Among the hotels surveyed were representatives from large international hotel chains to small family-owned hotels from big cities to rural areas. The study includes 51 hotels, conducting 51 one-hour interviews with hotel managers, shorter 5-15 minutes interviews with some staff members, on-site observation, and a review of various documents and information on websites and other documents about the hotels' operations.

An interview guide was constructed and was divided into the following themes/areas of questions: personal background (upbringing, including educational background, language skills, etc.), questions about the hotel (org. size, number of staff, years as a leader, development measures, etc.; sustainability (including questions such as what it is, what has been done in practice, how has the staff been trained, future plans for more sustainable operations, cooperation with other actors, what kind of help is desired, etc.). Observations were conducted by the researcher staying overnight at the hotels investigated. This abled observation and gathered knowledge of the room conditions and insight into the daily work towards sustainability at the hotel. Also, some shorter interviews were conducted with other personnel at the hotels. A total of 188 people were interviewed, consisting the number of interviewees ranged between three and seven people per hotel. Interviews included questions about what it was like to work at the hotel. How did they experience the leadership? How did they work towards sustainability? The secondary data material was gathered from hotels' web pages, guest reviews and printed documents on-site. This data material was analysed using theoretical concepts such as sustainability, mission

and responsibility understanding, leadership and value creation. Research questions on the data material consisted following themes: What is sustainability for respondents? How do they perceive the requirements for more sustainable hotel operations? How are the sustainability requirements implemented in practice? How is the staff trained in sustainability, and which processes are used to collaborate with customers and other actors? What can be read out about the leadership towards sustainability? This is a study with an exploratory purpose, i.e. how some hotels choose to prioritize or not work towards more sustainability by performing specific changes in their processes. The respondents' answers were then analysed using an abductive approach. Thematic content analysis based on the questions/themes requested and the theoretical concepts presented in the study were alternated. Ethical considerations: all hotels and their leaders and staff members interviewed are anonymized in this study.

4 PRESENTATION, ANALYSE AND INTERPRETATION OF THE RESULTS

In the following section answers from the 51 interviews with hotel managers, results from staff interviews and observations, and secondary data material is presented, analysed and interpreted.

4.1 Interviews with Hotel Managers

Firstly, there is an account of the compilation of results from questions on facts about the hotels, staff, the managers' years of service, educational background and language skills. Then questions about sustainability will be reported. Furthermore, the answers regarding the practical implementation and measures the hotels in question have implemented in terms of sustainability are explained. Finally, results that concern the measures that remain in the hotel's sustainability work are analysed.

The hotels included in the study were of different sizes, had several profiles, and were located in different geographical spots in eleven European countries. In total, 51 hotels were included in the study. On average, they had 50.6 rooms. The number of rooms varied between six and 161 rooms. Most of the hotels were family-owned. About 25% of the hotels had joined or had a franchising agreement with larger hotel chains, such as, e.g. Best Western and Hilton etc. Most of the hotels can be classified as three or four-star hotels. However, approximately 75% of this study were four-star hotels. One of the accommodations was a nunnery. Among the hotels were two castles. Countries including this study and the number of hotels in every country investigated: Italy (11), Slovakia (2), France (12), Poland (4), Greece (7), Holland (3), Germany (4), Romania (2), Belgium (2), Hungary (2) and Bulgaria (2). In total, 51 hotels in 11 countries were part of this study.

4.1.1 Age, gender, schooling and language skills of managers

Most leaders were between 50 and 60 years old. Regarding the percentage of the different age groups, the following results were prominent in the group of leaders. Age between 21-30 varied 13%, age between 31-40 varied 13%, age between 41-50 varied 16%, age between 51-60 varied 39% and age between 61-70 varied 19%. The respondents' gender distribution was 58% male and 42% female. The educational background of the leaders was 80% university degrees. Only 20% of the leaders had only a high school education or less. University studies were mostly about subjects as economics and administration; however, several managers had studied hotel business and management. Not all leaders could speak foreign languages, but the majority knew, on average, two other languages in addition to their mother tongue.

4.1.2 About the development of the businesses during the past five years

The time respondents have been working as managers of the hotels varies from 44 years to two months. If calculated the average years of service for these by removing the respondents with only two months in the hotel's service, the average number of years in service as a hotelier is 15.7 years. Development of hotel businesses over the last five years also varies greatly, not least due to the pandemic period. Regarding the development of these companies, the leaders state that during the past five years, including the years with the pandemic, the businesses have mostly grown and had good returns.

Nevertheless, a minority of leaders complain that they have bad finances and have to struggle with various things, most problems seeming to be caused by a lack of staff. All these hotels have received government financial assistance for staff costs during the pandemic. However, several managers testify that the personnel never returned after the pandemic. They chose to retrain, study or move abroad, etc. Approximately 19% of respondents' report that their finances are so bad that they consider selling their business. These businesses have not reinvested the profits in the hotels for several years in a row, are facing significant renovation needs and profile changes, and are unable to meet customer expectations. Some others have considered selling for other reasons. Their businesses, primarily family-owned, have no successors, even though it is believed that the business is excellent. Most leaders and hotel owners kept working at the hotels during the pandemic. Some were planning for future changes, and others were conducting significant renovations. Only a few of these 51 leaders stayed at home during the pandemic. Some of the hotels' staff offered their services during the pandemic even though they did not need to. Some came and renovated locations with their managers, and others took care of gardens, etc. They showed solidarity with their employers and wanted to do something during the day for their wages. The study shows that these hotels have had fewer staff members falling off than the other hotels.

These answers show that most leaders, with a few exceptions, have long experience as leaders in the hotel industry. Their level of education seems to be relatively high, but mostly in administration and economy-related subjects.

This fact also shows their main focus when managing their businesses. They are primarily involved in the financial management of the company. During the pandemic, most managers have worked continuously with various tasks. Several of them testify that they were given an opportunity and time for reflection under the lockdowns, which enabled them to think more holistically and reflect on their operations. This also allowed them to make new plans for the future. Several leaders commented that during the lockdowns, they were better off financially as the state paid the costs of the staff's salaries.

4.1.3 Sustainability

In this section, the responses to sustainability issues are presented. The following research questions have been guiding the interpretation of responses. What is sustainability for respondents? How do they perceive the requirements for more sustainable hotel operations? How are the sustainability requirements implemented in practice? How is the staff trained in sustainability, and which processes are used to collaborate with customers and other actors? What can be read out about the leadership towards sustainability?

There have been many discussions over the interpretation of the meaning of the concept of sustainability. There are as many answers as there are respondents. Many managers in this study refer to this question, naturally, by refereeing to their businesses. They are talking about ecological sustainability by pointing out the importance of thinking about energy and water use in their hotels. Many respondents also highlight the importance of thinking economically. Some managers are thinking about their behaviours and relate these to sustainable living by talking about how they have already changed their own behaviours. They are now cycling to work, sharing their car, not using too much energy, etc. Most hotel managers are aware of the four pillars of sustainability. However, only one is also talking about the ethical matters within the issue. Hotels' geographical location is also a factor which has been the eye opener for several managers: if there is a severe water shortage, hot climate etc., in the resort, it is often those things respondents take up with the interview. They are apprehensive over this and the implications of that to their economy.

4.1.4 How do hotels perceive the requirements for more sustainable hotel operations, and how are these implemented in practice?

About 20% of these hotels are connected to some certification system (e.g. Green Key or other systems) which also require sustainability measures. These hotels connected to these certification systems follow the regulations regularly and are evaluated by them. The others are working on more or less individual measures for sustainability. These can be about saving water/towels/electricity, demands printed through different kinds of signs and calls to action at the hotels. In addition, all hotels comply with the local authority requirements for more

sustainable handling of garbage, food waste, etc. All countries have regulations for hotels on the national level. They vary from country to country (e.g., France state is demanding that hotels reclassify their businesses every five years.They also ask for things to be done regarding sustainability issues). Half of the hotels seem to be in the process of improving their operations to become more sustainable. They change lamps and switch to water-saving toilets and showers. They have garbage sorting bins and use ecological cleaning methods and detergents. They make advertisements for local food and tours. They are planning charge stations for electric cars – the other half of the hotels' act is based on the external requirements for sustainability. The leaders desire, last but not least, more green technology.

4.1.5 How is the staff trained in sustainability, and which processes are used in collaboration with customers and other actors?

Only a handful of managers state that they involve the staff in the sustainability work other than assigning this as an additional assignment. They have not given them any training in sustainability knowledge and measures. According to the leaders, what is challenging is high staff turnover, lack of language skills, and young untrained and seasonal employees. Time is spent introducing the staff to the main work causing there is no time to train them in sustainability. The hotel managers also address their lack of knowledge on the subject. The time during the pandemic was not used for continuing sustainability measures, although many were renovating and planning other future operations. The managers explained this as something that was not prioritized as the fate of the entire business was uncertain. Some leaders expressed the need to find strategies to train their staff. The knowledge and desire to do so existed, but the know-how to fulfil the assignment was missing. Some others expressed that it was challenging to train the staff as they were used to the old working methods.

The guests' response to sustainability measures varies, according to the manager's statements and guest reviews on the websites. Some guests demand more sustainability measures, and others see this as a loss of the comforts and habits they are used to while visiting the hotels. The unreasonable sustainability requirements include, e.g. demand for the use of local products all year round, even though access to these is seasonal. The statements show that hotel guests have become more aware of sustainability while travelling. It seems to be the small, often family-owned hotels with the most environmentally and sustainable-conscious guests. As for other actors and stakeholders, managers expressed increased cooperation with municipalities and suppliers. Managers wanted a holistic approach to sustainability, and all processes should be sustainable. There are also good examples in this study among the leaders who work closely with surrounding society and the various actors. These managers promote local foods, a clean environment, and cultural and natural experiences for their hotel guests.

4.1.6 What can be read out about the managers' leadership towards sustainability?

In terms of leadership, managers can be divided into three major groups. A group of leaders clearly showed their commitment and were able to engage their staff in all processes at the hotel. They involved the staff in all plans, had clear goals for the business, and gave the staff some freedom, education and trust but also shared responsibilities among them. These leaders seemed to be sympathetic and forward-looking. They had a holistic view of the businesses. The second group seemed to be tied to the owners or regulations of the hotel. They did not involve the staff in the planning process but demanded a response by issuing orders. They behaved like marionette puppets without any own initiative in fulfilling the assignment. The third group consisted of leaders who had somehow given up their mission as leaders and apparently only administered the business. They had no foresight, no development or sustainability plans. Some of these managers planned their retirement, and others the business sale or administered the business only to collect the profit.

4.2 Interviews with the Staff Members

The hotel staff were interviewed through short, spontaneous meetings inside the locations. Questions included: How was it to work at the hotel? How was the leadership perceived? How did they work towards sustainability?

The majority of the answers reflect well the reality that could be observed in the hotels. Almost everyone complained about the heavy workload, lack of colleagues, the fast pace, and the lack of time for their duties. Many worked in several parts of the business: they served breakfast, cleaned the rooms, and worked at the reception or room service. There were also hotel staff who were satisfied with their workplaces. They expressed their contentment by saying they had good colleagues and used to help each other. The interviews revealed a significant staff turnover at most hotels, many new employees with poor language skills, lack of industry experience, and short-term employment contracts. The employees' knowledge and cultural backgrounds seemed to cause workplace problems. In the same work team, e.g. a low-educated boat refugee from Africa worked with a highly-educated war refugee from Ukraine.

The leadership was perceived as deficient by approximately 75% of the respondents. The reasons were the leadership's strictness, savings requirements, control measures, poor working conditions and low wages. Others expressed their gratitude for long and safe employment, leaders with whom they had a good relationship and were trusted. The result was poor in terms of knowledge and actual work towards sustainability. Only 10% of all respondents had good knowledge of sustainability in practice. They worked in hotels where it could also be observed that most measures for sustainability were already in use. The 90% again had a varied amount of knowledge about sustainability, everything from what it is to some showing a sign with a request not to leave the towel on the floor if you were thinking about sustainability issues as a guest.

4.3 The Secondary Data Material

4.3.1 Hotels' webpages

Guest reviews and on-site printed documents were studied to maintain more business information. The hotels in question had different types of websites. Some had only their own website with a booking system, while others used several international booking sites. The design of the web pages was of different quality but still contained the same facts about the business. Systems of the guests' reviews were also built up in a general way. They contain questions about amenities in the rooms, breakfast, restaurants, hotel location, length of stay, and the staff's treatment of the guests. They may include some empty answer boxes where the guests could write in some other issues. Nevertheless, none of these 51 hotels had questions about experiences regarding the hotel's sustainability work, not even the hotels that had otherwise progressed with their sustainability work. Sustainability issues were, though, visible on the hotels' websites, brochures, and various signs around the hotels, especially with the hotels that were part of some of the certification systems.

4.4 Observations at the Hotels

Observations at the hotels were carried out during the visits, which varied in length between 1 to 5 days. During the visit, external and internal facilities were observed, consisting of the physical spaces, the rooms, shared facilities, breakfast room, restaurant, gym, pool, parking facilities, garage, etc. Furthermore, the ongoing processes at the hotels were observed, e.g. how the reception, the cleaning, and the service in the different parts of the hotel worked. Physical spaces varied in appearance, size, equipment, condition and furnishings from one hotel to another. All the hotels visited had their breakfast room, approx. 80% of the hotels also had their restaurant. In addition, several hotels could have separate bars, gyms, garages, swimming pools, souvenir shops, conference rooms, etc. The maintenance of the hotels varied greatly. It was visible in several places (six of 51 hotels) how the hotels had stopped developing and only seemed to fix the absolute essentials to keep their business afloat. These hotels had significant renovation needs in all their premises, not least the rooms. The staff was reduced to a minimum, and the restaurant only served a light breakfast with cheap, mass-produced products.

5 CONCLUSION

The study shows that a few accommodation entrepreneurs have invested wholeheartedly in sustainability measures during the last five years despite the increased social debate about the importance of more sustainable living. In the study, 51 managers were interviewed in 11 different European countries. The results show some tendencies regarding the practical work for sustainability. In general, sustainability work has not achieved the desired results in practice due

to, among other things, a lack of knowledge, so-called greenwashing, disengagement, lack of personnel, financial losses due to pandemics etc. However, the study also shows good examples of entrepreneurs who have implemented significant changes in their organisations through active path choices, investments and knowledge acquisition and dissemination of it to their staff.

In the following, some challenges and possibilities are lifted due to this study of 51 European hotels and their work towards sustainability. The biggest challenge based on this study is the lack of knowledge about sustainability in practice. To absorb the knowledge, one must understand the task and its responsibilities (Abrahamsson and Andersen, 2005; Oxenswärdh, 2011). It is even more critical for leaders to understand this when communicating and interpreting sustainability goals with their staff.

This also requires systems thinking skills. This work can advantageously begin by defining what sustainability is in one's organisation. What can it mean in practice? Which system parts should it include, and which processes can be distinguished and worked with towards sustainability? (Rambaud and Richard, 2015; Appelbaum et al., 2016a; Oxenswärdh, 2017). For this purpose, a continuous learning process should be organised for the entire staff (Oxenswärdh, 2011, 2018; Naess, 1995; Gaziulusoy, Boyle and McDowall, 2013). Furthermore, sustainability can be seen as a value we co-create in groups and teams. A more systematic learning and innovation processes for value creation are needed, a change into a more practical work towards sustainable measures (Davison at al., 2014). Firstly, companies must incorporate sustainability into their vision to improve sustainability performance. It requires knowledge of why and how to incorporate it, then translating its overall objective into specific sustainability practices for each performance area. Finally, there is a need to control and measure indicators to assess achievement for each area (Gadenne et al. 2012). In sum, it is essential to start with knowing your system and learning from others. Work with your staff in constant collaboration and involve other stakeholders in sustainability work. It also requires courage to demand sustainable solutions with your suppliers and other stakeholders. Successful and well-founded sustainability work can enable an increased influx of customers and counteract so-called greenwashing. The hotels need to network with other hotels, not least, it would be fruitful to collaborate and learn from each other about sustainability measures in practice. Lastly, since many leaders are not professional change agents, it would be essential to develop leaders as change agents to manage a change process towards more sustainable practice successfully. A mature understanding of sustainability management requires adopting a multidisciplinary systemic lens capable of appreciating the interconnectivity of economic, political, social, ecological and ethical issues across temporal and spatial dimensions.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Application of Remote Sensing Data in Crop Yield and Quality: Systematic Literature Review

DOI: 10.12776/QIP.V26I3.1708

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Received: 2022-06-21 Accepted: 2022-06-29 Published: 2022-11-30

ABSTRACT

Purpose: Covering current state of the art in the field of application of remotely sensed data in crop quality improvement.

Methodology/Approach: Systematic literature review using novel text mining techniques.

Findings: Relevance of topic, measured by number of relevant studies, is rising, best performing input data types and modelling techniques are identified.

Research Limitation/Implication: Review to a certain point of time in a rapidly evolving field of research.

Originality/Value of paper: There was no similar review article on the topic at the time of conducting this research.

Category: Literature review

Keywords: satellite imagery; crop growth model; remote sensing; crop yield quality; precision agriculture

1 INTRODUCTION

Precision Agriculture (PA) is changing aspects of agriculture around the world through several potential benefits, such as profitability, productivity, sustainability, crop quality, environmental protection, and rural development (Liaghat and Balasundram, 2010). According to Cisternas et al. (2020), one of the most used technologies in PA is Remote Sensing (RS).

Jensen (1996) defined RS as "a scientific discipline discussing the acquisition and interpretation of information obtained by sensors that are not in physical contact with an observed object". This field of science includes aerial, satellite

and cosmic observations of the surfaces and atmospheres of the planets of the solar system, with the most frequently studied object being the planet Earth. RS technologies are usually limited to methods that detect electromagnetic energy, including visible and invisible radiation that interacts with surface materials and the atmosphere (Liaghat and Balasundram, 2010).

Data obtained by RS techniques can be used in variety of sectors besides agriculture: from urban and natural resources planning and natural disaster prevention (Solemane et al., 2019) to creating tools that help optimizing global supply chains, such as Global Copper Smelting Index.

RS technologies have biggest impact on crop quality. According to Munnaf et al. (2020), the key indicator of crop growth and productivity is crop canopy and its geometric characteristics. It has been proven by many researchers, that crop canopy is a potential crop yield indicator (Villalobos et al., 2006). From the perspective of remotely sensed agricultural data, satellite-derived vegetation indices are often used to monitor crop quality and predict crop yields.

2 METHODOLOGY

The goal of this study is to summarize models, input data and crop types researched in the relevant studies in the field of crop yield quality estimation (CYE). We conducted this study as a systematic literature review by adapting the framework of Kitchenham and Charters (2007).

Firstly, we created a plan for the review, which consists of composing research Questions (Q), defining sources of articles, and search and review protocols:

Q1: What are the most researched crop types?

Q2: What models are used in CYE?

Q3: What input data are used in CYE?

2.1 Search Protocol

First step was to extract keywords. Simple text mining tool was developed using Python programming language and Natural Language Processing packages, with full text of 15 previously found and highly relevant case studies as base data collection. In the next step, we performed text processing which consists of removing undesirable information (stop words), stemming and lemmatization. Finally, we evaluated the most frequent one-, two- and three-word terms.

Based on text analysis, we identified “remote sensing”, “satellite imagery”, “crop yield estimation” and “crop growth model” as the most relevant keywords. Selected terms were then combined into search queries (Table 1). Dataset of collected studies consists of 378 papers (after removing 43 duplicates).

Table 1 – Search Queries, Journal Repositories and Number of Studies

Repository	Search query	Papers
Web of Science	(TS=(((“remote sensing”) OR (“satellite imagery”)) AND ((“crop yield estimat*”) OR(“crop growth model”))) AND DOCUMENT TYPES: (Article)	132
IEEE Xplore	(((remote sensing) OR (“satellite imag*”)) AND ((“crop yield estimat*”)OR("crop growth model))	80
Science Direct	(“remote sensing” OR “satellite imagery”) AND (“crop yield estimation” OR “crop growth model”)[Journals]	209
Total		421

2.2 Review Protocol

Firstly, we defined 3 degrees of Relevance (R):

R1: Papers that are relevant for this research, but do not represent the main source of knowledge (e.g., RS technologies overview in general);

R2: Papers that are moderately relevant and adequate (e.g., previously conducted literature review on application of RS);

R3: Papers that are very relevant and adequate: actual case studies on application of RS data in CYE.

We decided to include every publication with Relevance 3 to this research; excluded were publications with Relevance 1 and 2. Subsequently, we reviewed abstracts of each publication to further relevance consideration.

By conducting this research, we found 108 highly relevant publication, that were subjected to further in-depth review. We reviewed full text of each publication to address all research questions.

3 RESULTS AND DISCUSSION

This section summarizes the results of the research. Firstly, we present general findings. After that, every research question is addressed.

The results shown that importance of RS and PA techniques used in crop yield prediction is increasing, based on the rising number of conducted case studies (relevance R3), as shown in Figure 1.

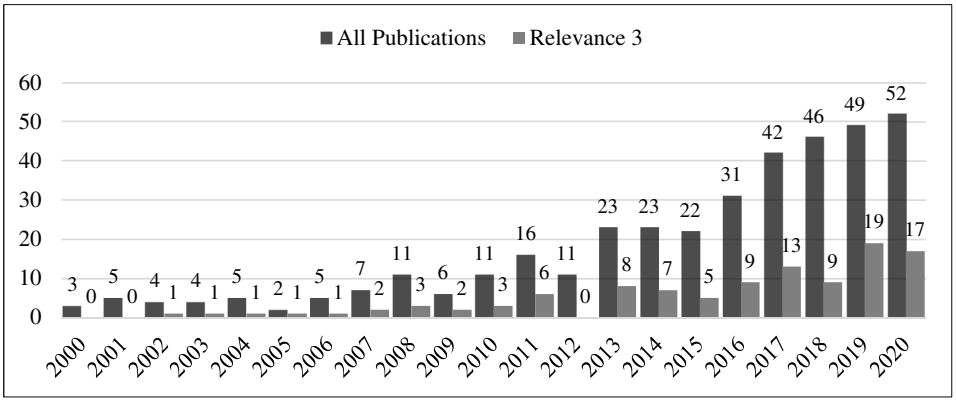

Figure 1 – Distribution of Publications per Year

Amid the selected publications, 52 were researching CYE models in Asia, with China (40) being the most researched Asian country, followed by India (5) and Pakistan (2). Second most researched continent is America, USA appeared in case studies 23 times and Canada four times. Fewer studies were conducted in Europe (13), Africa (13) and Australia (3).

3.1 Crop Types

It has been observed that seven publications did not explicitly indicate a specific type of crop. On the other side, 14 reviewed publications researched more than one crop at once.

We have identified a total of 16 different crop types. The most frequently researched crops were wheat, corn, rice, soybean, and cotton. This could be related to the researched countries, since, according to UN FAO statistics, China, India, and USA are amongst the biggest wheat and corn producers in the world. Results are shown in Figure 2.

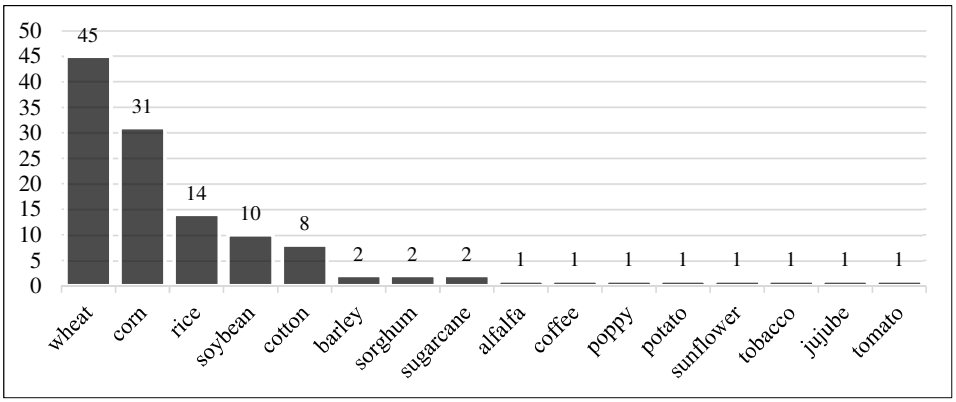

Figure 2 – Crops Mentioned in Reviewed Publication

3.2 Models

We have identified 19 different CYE models. Two main groups of estimation models were defined: existing models and custom models. Former group represents models, such as World Food of Studies (WOFOST) or Crop Environment Resource Synthesis (CERES), that simulate crop growth response to climate data, soil data, crop genotypes and field management across locations throughout the world (Basso, Liu and Ritchie, 2016).

Custom models are developed directly by researchers, using mainly regression analysis (REG) and machine learning techniques (ML). We have discovered that majority of researchers decided to develop their own model, with regression analysis being the most frequent one. However, as technology advances, more researchers are implementing machine learning techniques to estimate crop yield more precisely, as shown in Figure 3.

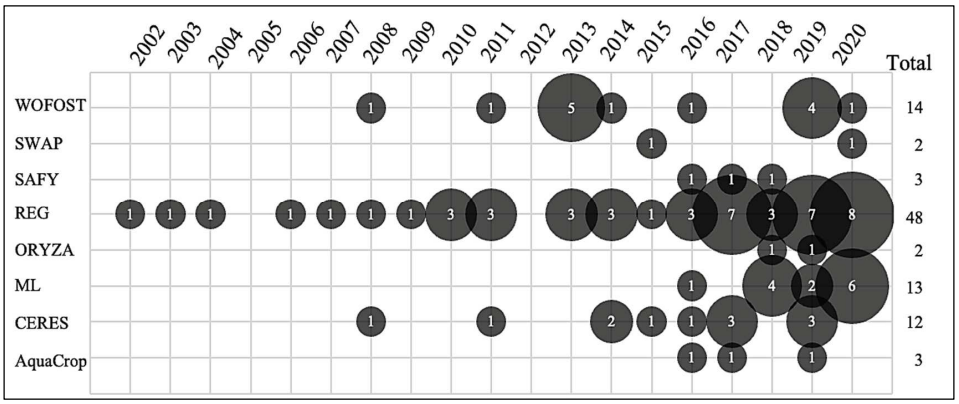

Figure 3 – Models Used in Reviewed Publications per Year

3.2.1 Regression models

We have identified linear regression and time series analysis as the most frequent approach to estimate crop yield.

Prasad et al. (2006) developed piecewise linear regression method with breakpoint for corn and soybean, considering Normalized Difference Vegetation Index (NDVI), soil moisture, surface temperature and rainfall data of Iowa state as input variables. To minimise inconsistency and errors in yield predictions, non-linear Quasi-Newton multi-variate optimization method is utilized, resulting in R^2 of 0.78 for corn R^2 of 0.86 for soybean crop.

Wang et al. (2010) discovered that linear regression yield prediction model based on canopy reflectance (represented by NDVI) of rice at booting stage in Taiwan was not significantly different from the 1:1 line. Although this model showed Mean Average Error (MAE) of 7.7 per cent for the first crop season and 13.1 per cent for the second season, authors state that the relation between spectral indices and CYE needs to be further verified.

Sakamoto, Gitelson and Arkebauer (2013) developed linear regression maize yield estimation model based on MODIS-WDRVI (Wide Dynamic Range Vegetation Index), which was assimilated with MODIS-based crop phenology detection Shape Model Fitting method (SMF). Additionally, correlation between MODIS-WDRVI and grain yield ($R^2 = 0.83$) was higher than the one based on ground observed green Leaf Area Index (LAI) ($R^2 = 0.66$). The best correlation was observed 7 to 10 days before silking stage of maize.

Holzman and Rivas (2016) created linear model for maize yield prediction in Argentina's humid large, cultivated areas using Temperature-Vegetation Dryness Index (TVDI) index data from MODIS/Aqua Enhanced Vegetation Index (EVI) products that was evaluated against official statistics. The authors claim that model can predict maize yield with reasonable accuracy (Root Mean Square Error – RMSE – from 12 to 18 per cent) 8 to 12 weeks before harvest.

Paul, Saha and Hembram (2020) developed regression model of rice yield prediction in India with self-constructed vegetation indices based on NDVI and EVI. Study revealed that the rice yield can be predicted with reasonable accuracy 30 to 60 days before harvesting.

3.2.2 Machine Learning Models

13 publications of 108 reviewed case studies implemented ML techniques in CYE models. As the most frequent ML technique we have identified Random Forest (RF), which appeared in nine publications.

Ngie and Ahmed (2018) developed CYE model using RF technique for maize yield prediction in South African fields with accuracy of $R^2 = 0.92$ adopting Soil-adjusted vegetation index (SAVI) and NDVI data. Results have shown that maize yield prediction was more accurate earlier on in the season (in March during the vegetative growth stage) in comparison to reproductive stage in June. As a possible explanation authors state the correlation between green pigment in corn leaves and its yields through photosynthetic activities.

Yu and Shang (2018) estimated annual maize and sunflower yield in China, implementing RF technique and vegetation indices. Eight models were developed: the most optimal model was based on NDVI time series data from the 120th day to the 201st day (with 10 days' interval). Optimal model for sunflower was identified as the combination of NDVI and phenological characteristics. The most important conclusion of this case study is that the yields of both crops could be well estimated 50 days before crop harvest. The accuracies (Adjusted R^2) of both estimation models varies from 0.80 to 0.90 at pixel level, and from 0.43 to 0.48 (maize) or from 0.61 to 0.68 (sunflower) at the county level, respectively.

In four publications, we have discovered usage of Neural Networks (NN). Koller and Upadhyaya (2005) predicted daily LAI values using artificial NN model, which were used as an input of analytical model for CYE of tomato. However, researchers discovered, that the correlation between actual and predicted yield maps was not very high ($R^2 = 0.29$). Reason for that might be the fact, that the

ANN model developed by researchers used only 1 neuron. Important to add, this study was conducted in 2005, NN as well as computational power have been developing significantly since.

More accurate results were accomplished by Bose et al. (2016). Researchers compared different modelling methods: Linear Regression, K-nearest neighbour algorithm (KNN), support vector regression (SVR) and spiking neural networks (SNN) with NeuCube computational architecture. As the best performing modelling method have been discovered SNN with correlation coefficient (R) of 0.81, RMSE of 0.29 and MAE of 0.24.

Peng et al. (2020) compared five ML algorithms: least absolute shrinkage and selection operator regression (LASSO), ridge regression (RIDGE), Support Vector Machine (SVM), RF and ANN. Results revealed, that nonlinear algorithms (RF, SVM, ANN) outperformed the linear algorithms (LASSO, RIDGE) for maize and soybean yield prediction. Sun et al. (2020) proposed model employing convolutional neural network (CNN) and recurrent neural network (RNN). Although CNN cannot learn temporal patterns and RNN can barely learn spatial characteristics, both techniques can be adopted in a multilevel deep learning network (MLDL) model to extract both spatial and temporal features, including time series RS data and soil data to predict crop yield. Researchers evaluated model in U.S. Corn Belt states: MLDL model outperformed deep neural network (DNN) as well as LASSO, RF and RIDGE models with R^2 up to 0.78.

Leroux et al. (2019) compared linear and nonlinear (RF) statistical model for corn fields with RF technique being more accurate thanks to ability to account underlying eco-physiological processes in vegetation development. In addition, soil data (such as soil moisture) contributed to improving RF corn model. Similar results were accomplished by Sakamoto, Gitelson and Arkebauer (2013) for corn and soybean in USA.

Jiang et al. (2019) compared deep learning long short-term memory (LSTM) model performance with LASSO regression and RF technique for annual yield estimation across the U.S. Corn Belt. The main advantage of LSTM model is the ability to estimate yield under extreme weather events, such as historically low values of precipitation or killing degree days occurred in 2012 in researched area. LSTM model achieved the highest R^2 of 0.66, in comparison with LASSO (R^2 = 0.63) and RF (R^2 = 0.58).

According to Shao et al. (2015), selection of model (linear regression or ML techniques) depends on number of variables. If the number of variables is limited, linear regression model may work well. When the number of variables increases, the model becomes more complex and using ML techniques (such as RF) is recommended. However, authors did not identify the exact breaking point in number of variables.

3.2.3 Crop Growth Models

Our research revealed, that the most frequently used existing model was WOFOST. According to Yuping et al. (2008), WOFOST model provided more accurate estimates of winter wheat yield when remote sensing data are included during the growing season. Similarly, Ma et al. (2013) accomplished more accurate results implementing MODIS-LAI instead of simulated LAI inputs, although one of the disadvantages of MODIS-LAI approach is the residual error resulted from the mixed pixel effect.

CERES is an eco-physiological model that simulates crop phenology, total above ground biomass and yield using carbon, nitrogen, and water balance principles. Base CERES model uses similar inputs as WOFOST: weather, soil, and cultivar data. Case studies have shown that best results are accomplished when using both MODIS-, MERIS- or ASAR-derived LAI and vegetation indices such as EVI or NDVI (Dente et al., 2008; Fang, Liang and Hoogenboom, 2011; Jin et al., 2016a; Ban, Ahn and Lee, 2019).

AquaCrop is a water-driven crop growth model aimed at improving crop water management strategies in irrigation regions. Inputs are meteorological data, soil data, crop parameters and field management data. Jin et al. (2016b) researched winter wheat yield prediction using AquaCrop model and discovered, that the best performing spectral index was Normalized difference matter index (NDMI). Luciani, Laneve and JahJah (2019) used NDVI time series derived phenological data in AquaCrop model with R = 0.699 for corn and R = 0.723 for wheat. However, authors stated, that model performances could be unsatisfactory in severely water-stressed environment.

CROWRAYEM is an abbreviation of Crop water requirement analysis yield estimation model, based on CROPWAT modelling software, which uses climatic data and the crops' yield response to estimate yield (Eze et al., 2020). The research has been conducted in Ethiopia for sorghum and barley. Both crop types performed relatively well, with R^2 coefficient of 0.85 (sorghum) and 0.86 (barley).

3.3 Input Data

We have identified 11 types of vegetation indices that were used as an input in various CYE models. The most frequent vegetation index is NDVI, which appeared in 75 of 108 publications, followed by LAI (53 publications) and EVI (18 publications). Results showed that the importance of NDVI and LAI is increasing in recent years, with both indices being used in more studies published in recent years (Figure 4).

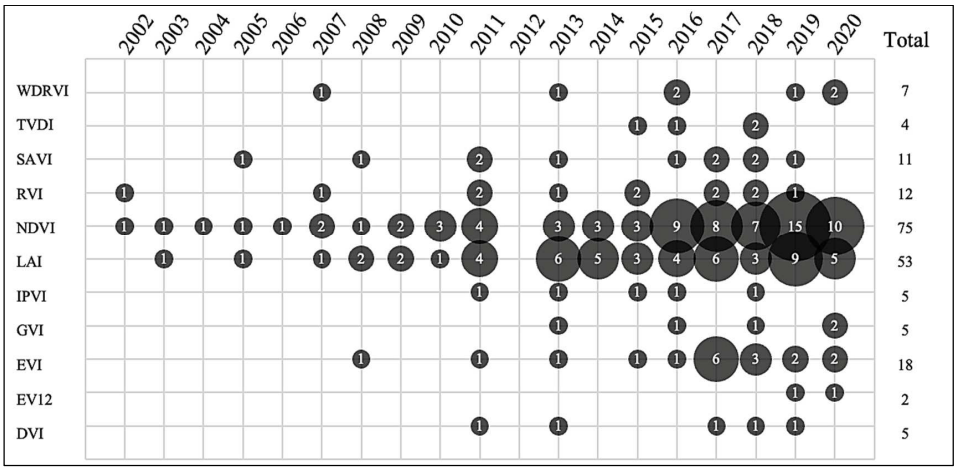

Figure 4 – Distribution of Input Data per Year

Gontia and Tiwari (2011) developed two linear regression models to estimate wheat yield in India using NDVI and SAVI as inputs. Results revealed that SAVI-based model could predict crop yield more accurately compared to that based on NDVI. Reason for that might be ability of SAVI values to adjust the soil reflectance.

Noureldin et al. (2013) compared different vegetation indices in rice yield estimation regression models for the season 2008 and 2009. Validation analysis of each model showed, that using multi-regression model of LAI as one input and NDVI or any other vegetation index calculated from red and near infrared spectral reflectance during the period of the maximum vegetative growth accomplished the best results. However, to achieve the best accuracy of model, using high resolution satellite imagery is necessary.

Holzman and Rivas (2016) studied relationships between the TVDI and corn yield. Statistical significance was found, although the strength of the correlation in analysed counties of Argentina varied with the agroclimatic zone. The values were 0.73 (semi-arid area) and 0.83 (humid area), respectively.

Liaqat et al. (2017) compared spectral indices SAVI, MSAVI, NDVI and EVI in linear regression model for wheat in Pakistan. SAVI developed the best relationship which previously reported wheat yields amongst studied indices. Furthermore, researchers studied accuracy of SAVI obtained from Landsat 8 satellite and MODIS database. Evaluation of Landsat 8 images illustrated better relation ($R^2 = 0.743$) compared to model yield estimation by MODIS ($R^2 = 0.63$).

Shrestha et al. (2017) developed regression model with NDVI as an independent and corn yield dependent variable to predict corn yield loss due to the flood in studied area. Results showed that NDVI can estimate corn loss in flooded areas with high accuracy.

4 CONCLUSION

PA is one of the most important trends in the direction of the food sustainability and quality improvement. As the population of the Earth growths, so do the food requirements. PA offers many frameworks and tools that help achieve this goal, with remote sensing being one of the most important. Usability of remote sensing technology is extensive: from urban and natural resources planning and natural disaster prevention to agriculture industry optimization.

This study provides knowledge on the state of the art regarding the crop yield estimation using remote sensing technologies as well as identifies current trends in research. Firstly, we have identified 3 main research questions:

- What are the most researched crop types?
- What models are used for CYE?
- What input data are used in CYE?

We have implemented a novel approach using Python's natural language processing packages to extract keywords from previously found case studies. By inserting extracted keywords into search machines, we have found 378 articles in total. As our research revealed, this scientific field has grown in importance in recent years: while 20 years ago were three studies published, in 2020 alone we have found 52 publications on the topic.

As our research showed, there has been exponential rise of research over the years on CYE using RS data. This can be observed through the amount of publication that we found using relevant keywords.

Researchers study many different crop types with wheat and corn being the most frequent; develop different regression models and engage machine learning and artificial intelligence techniques to predict crop yields more and more accurately. On the other side there are many existing crop yield/growth models that report reasonably accurate estimations, such as WOFOST or CERES, that can be modified to fit the specifics of a crop type to further enhance the accuracy of forecast.

We have discovered, that remotely sensed data emerged as variations of spectral vegetation indices, that are more unified and more usable in crop yield forecasting. Different vegetation indices report different accuracy for different crop types, even in different parts of the world. We have identified the most important spectral vegetation indices, that can be used to predict crop yield, as well as potential sources.

The results of the systematic literature review allow to identify multiple future work research in context of CYE using RS data. Namely, focusing on crop types that have not been researched as often, such as barley, sugarcane, potato, or sunflower or creating model that is able to identify type of crop and automatically suggests needed input data. This can be done by implementing

convolutional neural networks, that are able to extract spatial and temporal features from multispectral images. Another important aspect that future research should focus on is the impact of predicted yield and estimated health of crop on global supply chains. This can lead to optimization of pesticide use and hence to better food quality.

ACKNOWLEDGEMENTS

This paper was supported by the project SmartAgriHubs under the No. 2282300354-EXPAND-6.

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Conceptualization, R.D. and A.Č.; Methodology, R.D.; Software, A.Č.; Validation, R.D.; Resources, R.D. and A.Č.; Data curation, A.Č.; Original draft preparation, A.Č.; Review and editing, R.D.; Visualization, A.Č.; Supervision, R.D.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Innovative Approaches to Management of Virtual Teams Leading to Reliability and Retention

DOI: 10.12776/QIP.V26I3.1734

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Received: 2022-08-10 Accepted: 2022-11-04 Published: 2022-11-30

ABSTRACT

Purpose: The paper focuses on identification of variables affecting management leading to reliability and retention of virtual teams.

Methodology/Approach: The data were collected globally from 323 managers working with virtual teams; members were hired and worked fully virtually with team members from different countries and time zones. Respondents were from all continents. The data were evaluated by tested by reliability tests and two and multidimensional statistics (Spearman's correlation, principal component and factor analysis).

Findings: Empowerment and encouraging were proven as variables significantly affecting management of virtual teams' reliability. Variables leading to employee retention are communication, performance appraisal, career plans, training and leadership/supervision to overcome barriers. Efficient management in virtual environment is significantly related to policies and career possibilities. Over 20% of managers are incompetent to work with virtual teams. The main threat leading to failure of virtual teams is burn out based on social distancing.

Research Limitation/Implication: Limitation of the study is the first approach to the virtual teams' management only focusing on ICT employees. The findings revealed significant relations leading to virtual operations impacting employees' performance, reliability and retention.

Originality/Value of paper: This paper provides an insight into the importance of innovative approach to virtual teams, as virtual employees may strive with low social contact and less support from organization.

Category: Research paper

Keywords: virtual teams; human resource management; retention; remote; reliability

1 INTRODUCTION

Virtual teams are becoming an integral part of modern organizations. After the Covid-19 era, management in virtual environment have been considered a necessity by organizations. Past years, even pre-Covid, global organizations invested significant amounts of money and sources to support smooth operation of virtual teams and virtual managers. The global outreach of Covid and use of communication technology for continued operations has further facilitated the idea of remote workstations where employees are working in the geographically differentiated regions but stay online and work together on organizational goals.

A number of studies show that managing virtual teams is more difficult than managing collocated teams, as leaders have less influence and less information about the status of the team; process management and team dynamics can be impaired; it is difficult to set up practices to uncover and resolve conflicts, motivate team members and monitor members' performance; it is difficult to build trust and team cohesion – see Davis and Bryant (2003), Zaccaro and Bader (2003), Zigurs (2003), Dulebohn and Hoch (2017). These problems are closely related to the reliability of virtual teams and the retention of employees in the organization and management need to focus on specifics of virtual teams (Gilson et al., 2015).

The aim of this paper is to is to test variables affecting management of virtual teams and significantly impact virtual teams' success. The research formulates and tests hypotheses revealing variables affecting virtual teams' reliability and retention.

The study tests model of management in virtual environment. The model is build and analysed based on factor analysis. This paper contains a review of the existing literature, presents methods followed by results, that are further discussed and conclusions are presented.

1.1 Theoretical Background

Virtual teams represent a work arrangement where team members are geographically dispersed, have limited face-to-face contact, work interdependently, and use electronic communication media to achieve common goals (Dulebohn and Hoch, 2017). Within virtual teams, knowledge workers collaborate despite time and distance to combine efforts and achieve a set goal (Bell and Kozlowski, 2002). The use of virtual teams holds great promise for the future (Dulebohn and Hoch, 2017). Mobility and flexibility are examples of megatrends that influence everyday life and also intensively change the way we work (Großer and Baumöl, 2017). The use of virtual teams thus represents a new chance in this context. For employees, this is associated with flexibility (regarding location and working hours), for organizations in an increasingly digital environment, it means competitiveness (new technological opportunities, employee retention, cost efficiency). From the point of view of competitiveness

on the labour market, it is about offering a work environment that provides time flexibility. The deployment of virtual teamwork is not only supported by technological and societal changes, but also seems relevant for employee retention (Großer and Baumöl, 2017).

Employee retention was described by James and Mathew (2012) and Bidisha and Mukulesh (2013) as a process in which employees are encouraged to remain with the organization for the maximum period of time (or until the project is completed). Mita, Aarti and Ravneeta (2014) defined employee retention as "a technique adopted by businesses to maintain an effective workforce and at the same time meet operational requirements". In the context of virtual teams, these are techniques within an organization that enable effective work teams to be maintained while meeting operational requirements. Based on impact of Covid-19, employers take steps to ensure that employees stay with the organization as long as possible (Alferaih, Sarwar and Eid, 2018; De Smet et al., 2021). According to Anitha (2016), virtual employee retention is not easy as the workforce is becoming more confident and demanding due to changes in markets and demographics. The employee retention process (in the context of virtual teams) represents a strategic tool for the success of the organization (Aburub, 2020). Kossivi, Xu and Kalgora (2016), described factors determining employee retention: management/leadership, conducive work environment, social support, development opportunities, autonomy, compensation, work-life balance and employee training and development. Attention has been paid to manager's leadership style, the organization's commitment to social responsibility, autonomy, work-life balance and technology (Khan and Wajidi, 2019; Valentine and Godkin, 2017; Kim and Stoner, 2008; Koubova and Buchko, 2013; Haar and White, 2013). According to Lee et al. (2022), there are still no studies that examine the effect of all these factors on employee retention and the underlying mechanism of these relationships. There are also no studies focused on this issue in the context of virtual teams. That is why this study was conducted. Based on the above mentioned, the following hypotheses on variables impacting management of retention of virtual teams were stated:

H1 (retention): Virtual team retention is related to positive perceptions of current employer.

H2 (retention): Virtual team retention is related to motivation and willingness to stay at current position.

Sishuwa and Phiri (2020) identified the main factors influencing employee retention, but also developed a framework based on a causal model and recommended possible solutions. Authors found that job satisfaction, organizational commitment and workplace structures are important for employee retention; however, individual characteristics did not have a significant influence on employee retention. Howard-Grenville (2020) emphasizes the need to focus on research into organizational dynamics among remote workers in order to explore the role of cultural factors in shaping remote workers' interactions.

Pianese, Errichiello and da Cunha (2022) discuss five "control domains" – control systems, supervisory management styles, trusting relationships, organizational identification, and work identity. They conclude that the management of remote workers represents a shift from direct supervision to management by objectives, and is linked to a leadership style that emphasizes trust-relationships and the empowerment and self-control of remote workers. Further, the organizational and managerial approach emphasizes the autonomy of remote workers, and empowerment often co-exists with a strict control (Porter and van den Hooff, 2020). Pianese, Errichiello and da Cunha (2022) stated that behavioural control promotes overcoming tensions and misunderstandings in cross-cultural teams, the study has shown the importance of combining technocratic control with socio-ideological control, based on informal sharing of norms, beliefs and values among team members, trusting relationships and team identification, which strengthens alignment of individual and collective goals. The ability of leaders to support and empower of virtual team members during virtual meetings and through electronically mediated communication is essential for this soft form of control. According to Arunprasad et al. (2022), stressed the need to develop conceptual frameworks related to the influence of culture on the remote work implementation and collaboration. O'Neill et al. (2016) adds that effective communication helps to build reliability and commitment, and interaction plays a crucial role, which was confirmed by Watson-Manheim, Chudoba and Crowston (2012) and Olson and Olson (2013). Based on these studies, the role of reliability in management of virtual teams will be tested by the following hypotheses:

H3 (reliability): Virtual team reliability is related relevant periodic performance appraisal.

H4 (reliability): Virtual team reliability is related to clearly communicated policies.

This paper focus on identification of variables affecting efficiency of management of virtual teams. Current research has shown that virtual teams present a number of challenges compared to collocated teams (Newman and Ford, 2021). Appropriate approaches to human resource management (Bulińska-Stangrecka and Bagieńska, 2019), knowledge sharing and collaborative culture (Kim, Billinghurst and Lee, 2018) contribute to building a sustainable competitive advantage through innovation management. These aspects also need to be addressed in the context of remote work management and appropriate systems and procedures need to be designed and implemented (Arunprasad et al., 2022).

In the context of the above findings and relations, this paper defines and tests the main variables affecting quality management and impacts virtual teams' retention.

2 METHODOLOGY

This study is based on questionnaires investigation of global managers working with virtual teams. The data were collected globally from 323 managers. Companies were selected based on their global operations and focus on ICT. The teams were considered virtual when members were hired and worked fully virtually with other team members from different countries worldwide and through different time zones. The sample was defined using Cochran's formula. The survey was used due to the fact that it was difficult to reach out to managers in dispersed locations worldwide (Saunders, Lewis and Thornhill, 2015). The questionnaire was designed to monitor actions of managers of virtual teams to lead employees online including focus on their welfare, the quality of interactions, impact of online work on satisfaction, reliability and factors impacting retention in virtual environment. Respondents were asked to provide their insight into their remote management and employee experience, distractions, reliability, performance appraisal and retention. Respondents had to indicate their views on recommending other people to work in their companies, organizational culture, remuneration, satisfaction on current position or possibility of external mobility.

The questionnaire had six identification questions, and ten main sections with 5-10 closed-ended Likert-scale sub-questions per each section. The scale was designed having five points from strong agreement to strong disagreement (see Tab. 1). The whole questionnaire and each sub-section were tested for validity using the Cronbach's Alpha (CA) test. As the whole questionnaire and each sub-section reliability reached value over 0.9, it was considered reliable and used for statistical analyses (Sullivan, 2011). The Pearson correlation (r) method was used to test relationships between the variables.

Table 1 – Questionnaire on Management of Virtual Teams Design and Validity

Category	**Sub-Category**	**No. of questions per category**	**Reliability**	**Validity**
Management in virtual environment	Quality of virtual interactions	11	CA 0.996	<0.05
	Responses to changes in remote work	9	CA 0.960	<0.05
Impact on Reliability	Policy of home office	4	CA 0.979	<0.05
	Distractions at home office	12	CA 0.997	<0.05
	Impact on performance	10	CA 0.984	<0.05
	Effects on psychic	6	CA 0.997	<0.05
Impact on Retention	Recommendation of the employer to friends and retention ability	7	CA 0.981	<0.05

2.1 Data and Sample

The data were collected online (CAWI) to employees who are working in virtual teams. The population and sample size was developed according to Cochran (2007) formula. Counting with (p = 0.5) and taking 95% confidence level the required sample size is 384 respondents for unspecified total size of population. This formula was then adjusted to limited sample size. The test finally shown 254 responses. The final sample of presented survey is 323 responses. Therefore, it can be considered as representative.

All respondents were employees between ages of 18-65 years old, working in virtual team and they are managed virtually. The study respondents consisted of; 156 males (48.3%) and 167 females (51.7%). According to age groups, 43.0% of the respondents (139) were in age group 21-38, 43.3% (140 respondents) were aged 39-56 and 13.6% (44 respondents) were aged 57-65. Respondents came from all continents Africa, North America, South America, Asia, Europe, and Oceania; more specifically: EU, UAE, Mexico, South America, Australia, Oceania, India, Canada, Middle East, China, Russia, Kazakhstan and African countries. Respondents were asked to fill the questionnaire when they were working in different countries than they were located and teams contained members from different countries. Thus, the questionnaire goal was to reached out to maximum diversity of countries to simulate diverse virtual environment. The main business were 18% operations, 11% support services/administrations, 10% IT, 9% finance, 6% sales, manufacturing (5%), quality (5%), supply chain (4%), marketing (4%), legal (5%), R&D (3%), HR (2%) and 18% indicated they work in different business operations that does not match given categories (i.e. education, healthcare, entertainment, agriculture, hospitality and others). According to size of company, 19% were small organizations (1-49 employees), 35% medium-sized organizations (50-999 employees), 46% in large organizations (over 1,000 employees). The questionnaire was anonymous.

2.2 Data Analysis

All survey results were processed in SPSS and Excel. Firstly, the data table was checked for missing values and unfinished questionnaires were excluded from the data file. The questions and their constructs were tested for their internal consistency by Cochrans's Alpha. All coefficients were reaching value over 0.9 showing adequate level and therefore the data were used for analyses. To evaluate the data, Spearman's coefficient was used, Pearson's test, and ANOVA. Based on satisfactory results of consistency tests and correlations, a multi-dimensional analysis was used. The multi-dimensional analysis was conducted using component analysis and factor analysis with Varimax rotation. The process of calculation and interpretation of results was processed according to Anderson, Fontinha and Robson (2019), Mishra et al. (2019) and Bell (2019).

To test relevance of data for factor analysis, the Kaiser-Meyer-Olkin test was used. The resultant value reached over 0.8. Thus, the data could be used for

multivariate analysis. Factors explain variability and dependence of considered variables. Theoretical factors were created (see Table 1) and further tested by factor analysis. The final output factors were reduced using the Maximum Likelihood Factor Analysis with Kaiser Varimax Rotation with a goodness of fit. For the selection of substantial factors, the Kaiser-Guttman rule was applied (i.e. substantial factors having a value within the range higher than 1) and subsequently the Sutin test was applied. The correlation coefficients are in the interval from <-1;1>. If the correlation coefficient is positive, it shows a direct proportion; negative shows indirect proportion. For the evaluation, the value of variable correlation higher than 0.3 (moderate correlation) according to Anderson, Fontinha and Robson (2019) was used. The data analysis was run by SPSS Statistics 22.

3 RESULTS

The results of presented study focus on variables that affect virtual teams' retention and reliability. The Tab. 2 shows first perceptions of managers on virtual management, where 1 mean not important and 6 stands for key emphasis of managers to attract virtual teams' members.

Table 2 – Perception of Management Quality in Virtual Environment

	N	Minimum	Maximum	Mean	Std. Deviation
Quality of interactions	323	1.000	6.000	4.432	1.035
Measures taken by organisation to adapt to virtual environment	323	1.000	6.000	4.105	1.127
Homework policy	323	1.000	6.000	4.071	1.253
Remote working experience	323	1.000	6.000	4.248	1.076
Distractions in home office	322	1.000	6.000	3.937	1.001

Notes: N – number of respondents.

According to the results, the most important according to managers working with virtual teams is quality of interaction. On the other hand, the threat of distractions is reported less in the studied sample.

The correlation analysis shown that emphasis has to be paid to quality of management of virtual teams that has to focus on the variables significantly affecting virtual teams' retention and reliability. Variables significantly impacting virtual teams' reliability are quality of interactions ($r = 0.714$, $p = 0.000$), homework policies ($r = 0.634$, $p = 0.000$), clear goals ($r = 0.487$, $p = 0.000$), fair treatment ($r = 0.657$, $p = 0.000$), access to trainings ($r = 0.658$, $p =$

0.000), clear career path (r = 0.502, p = 0.000), communication and feedback (r = 0.487, p = 0.000).

The presented data show that managers of virtual teams face new approaches of employees (i.e. 17% are unsuitable to fit virtual conditions – see Tab. 2), changed needs and requirements (online supervision, changes in motivation a communication that shift to individualized periodic goals, reskilling and upskilling and performance appraisal) that require new managerial skills. Attention has to be paid to employees' mental state and socialization during distance work (approx. 20% of employees are threatend by mental problems and burn-out syndrome – see Tab. 3), their motivation through possibilities for development and career progression (over 65% of employees are motivated by career opportunities), commitment and job satisfaction which proved to be the most influential areas of employee reliability and retention (r = 0.4 to 0.5).

Factors affecting employee retention are according to the survey results mainly impossibility of career development (33%) and 24% rely on unsatisfactory remuneration, while 22% refers to unreliable manager relationship. Two third of respondents stated that the possibility of career development is crucial for them to stay at current job position. Impossibility to grow makes over 60% of respondents to search for another job elsewhere. Even when teams are meeting only virtually, there is a crucial need for clearly communicated development plans and meetings with manager in order to discuss current and future progress and perspectives.

Retention is significantly related to positive perception of current employer (r = 0.634, p = 0.000; H1 accepted) and motivation and willingness to stay at current position (r = 0.332, p = 0.000; H2 accepted). The analysis shown that management of virtual teams relies heavily on career management. The mean importance of this factor was the highest from all other searched areas (4.329). Main factor leading to employee mobility in virtual teams is lack of career opportunities.

To ensure reliability of virtual employees, managers need to focus on remote working experience, challenges while working from home, virtual evaluation and impact on the performance appraisal, and other impact of remote work on personality. All mentioned areas are playing significant role in reliability in virtual environment (all averages and means were reaching over 4 out of scale where 5 means the highest value (strong agreement). The correlations between reliability and relevant periodic performance appraisal are strong and significant (r = 0.634; p < 0.001) (H3 accepted). The tests also confirmed that clearly communicated policies for virtual teams are statistically significant predictor ($F(4, 315) = 54.431$, $p < 0.001$)) of work experience and home office (H4 accepted). Respondents indicated that empowerment and encouraging is the most important strategy to enhance reliability of virtual teams.

The data were further processed by multivariate statistics. The model is significant as Kaiser-Meyer-Olkin (KMO) test value exceeds 0.9, Bartlett's test

p-value is 0.000. The correlation analysis provided adequate level of relations among tested variables and their significance. Sutin test was used to calculate final number of resultant factors. The four final factors are in Tab. 3. Totally, 54% of the variance was explained.

Table 3 – Factors Describing Management of Virtual Teams

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Clear goals, and periodical performance appraisal	**0.671**	-0.043	0.128	-0.112
Opportunity to grow at current company	**0.622**	0.053	0.201	**-0.302**
Fair treatment regarding trainings, awards	**0.756**	-0.194	0.129	0.017
Recommend a job at current company	**0.693**	-0.226	0.111	0.046
No interest and pleasure in doing work	-0.151	**0.763**	-0.072	-0.010
Emotionally drained from work	-0.106	**0.782**	0.183	0.150
Difficulty concentrating on the work	0.100	**0.719**	0.196	-0.107
Burned out from my work	-0.110	**0.797**	0.097	0.148
Adequate career path and promotion plan	**0.683**	-0.050	0.210	**-0.352**
Online training programs organized to improve performance	**0.610**	0.095	0.110	-0.237
Supervisor helps in identifying and bridging the performance gaps	**0.633**	0.093	0.005	**-0.360**
Targets are communicated very clearly	**0.671**	0.055	-0.087	**-0.354**
More productive working from the office	0.279	0.125	**0.617**	0.166
Always get feedback, correct communication channels	**0.700**	0.040	-0.270	0.152
Comfortable working with teammates as virtual teams	**0.481**	0.205	**-0.563**	0.070
Overall morale in the company is good	**0.718**	-0.147	0.059	0.189
Able to reach full potential whilst working remotely	**0.433**	0.259	**-0.687**	-0.019
Company is able to attract high-quality employees	**0.693**	-0.078	0.050	0.072
Good access to HR for advice and assistance	**0.683**	0.011	0.019	0.214
% Of variance	31.601	10.841	6.202	4.679
Factor name	Efficient VT	Burn out VT	Unsuitable for VT	Incompetent VM

Factor 1 describes efficient management in virtual environment. It is formed by clear goals, performance appraisal, career development opportunities and support in career progression that includes training programs organized to improve performance, supervisor helps in identifying and bridging the performance gaps and clear communication. Factor 1 is related to adequate fit with team members, good morale within the team and in the company, possibility to reach HR department in case it's necessary. Efficient VT is defined mainly by clear communication, set goals and performance appraisal, career plans, progression and training or supervising to overcome barriers. One third of the sample was able to create and maintain this clear efficient virtual teams. Variables in factor 1 focus on internal strategic HR management of development and career progression.

Factor 2 describes 11% of sample threatened by burn out in the virtual environment and shows inappropriate management of virtual employees. It points out no interest in virtual work, emotional drain, and difficulties concentrating. This shows inappropriate recruitment for virtual teams. Factor 3 show that 6% of respondents are not a good fit for virtual team, are less productive online, not comfortable to cooperate virtually and not able to reach their full potential online.

Factor 4 defines incompetent management given virtual conditions. The main problems are no opportunity to grow, no career path and promotion plan, impossibility to address problems and no supervision nor help, lack of clear communication and lack of trainings and development. The factor analysis points out management failures within management of virtual teams: incompetent recruitment, lack of communication, lack of carrier possibilities. Virtual employees are usually highly qualified and skilled labour force with clear vision of their growing potential. Management should support VT to achieve high performance to get reliable and loyal employees.

4 DISCUSSION

This paper discusses innovative management practices related to retention and reliability of virtual teams. Four hypotheses were tested; two related to virtual teams' retention and two referring to virtual employees' reliability. All four hypotheses were accepted. Results show that virtual team management heavily relates on positive perceptions of current employer (H1), motivation (H2), clear carrier plans and relevant periodic performance appraisal (H3) and clearly communicated policies for virtual teams (H4 accepted). The results are in line with relevant researches. The detailed results are further discussed in the area of retention and reliability.

The influence of motivation and positive perception of employer on employee retention must be taken into account (Shah and Asad, 2018), which is in line with this study (H2 accepted). In case employees perceive lack of career perspectives,

it leads to low retention or low reliability. This study shows that skilled and proactive communicating managers are the key to success of virtual teams. In virtual environment, managers need to focus on how to lead and motivate geographically dispersed team members. Relation-oriented leadership behaviours have been identified as a key factor for effective virtual leadership (Bartsch et al., 2021), as tested and accepted by H1. This study found that managers need to pay attention to personalized periodical appraisal, fair treatment, periodic online trainings and development to improve performance, help to overcome performance gaps and promote an atmosphere of social support.

Employee reliability is impacted by the workplace environment, supervisor, and the opportunity for development (Malinen, Wright and Cammock, 2013; Shuck and Albornoz, 2007; Carnevale and Hatak, 2020), which is in accordance with the results of this study. Aburub (2020) emphasizes that employee engagement is related to company policy, culture, leadership style and strategic human resource management tools, (confirmed by H3). This paper results add factor of communication, in line with Powell, Piccoli and Ives (2004).

To avoid burnout in virtual teams, it is essential to establish an atmosphere of collaboration and provide team with the necessary autonomy (Liao, 2017). Support of employee motivation leads to reliability. Managers are required to adapt their leadership style to the requirements of virtual teamwork (Kauffeld et al., 2022) to training needs of their staff, which was tested and accepted by H4.

5 CONCLUSION

The findings in this paper tested and confirmed variables affecting reliability and retention of virtual teams. According to respondents, the most important in virtual teams' management is quality of interaction. The correlation analysis shown that quality of management of virtual teams is affected by the variables homework policies and overall organizational policies in relation to virtual work, clear goals, fair treatment, access to trainings, clear career path, communication, and feedback.

Significant portion of virtual employees strive with low social contact and less support, as over one fifth of managers of virtual teams lack competences to manage virtual employees in fully online environment.

The factors affecting virtual teams' reliability is impacted by positive perceptions and references of current employer (H1), motivation and willingness to stay at current position (H2). Virtual teams' retention is affected mainly by clear carrier plans and relevant periodic performance appraisal (H3), and clearly communicated policies for virtual work and home office (H4).

Quality management of virtual teams has to primarily focus on reliable employee–manager relationship. Periodic discussions on plans, updates, performance appraisal and career development are crucial for virtual team

retention. Impossibility to grow makes over 60% of respondents to search for another job. There is a crucial need for periodic team and individual meetings with manager in order to discuss current and future progress and perspectives. Respondents indicated that empowerment and encouraging is the most important strategy to enhance reliability of virtual teams. The key to virtual employees' retention and reliability are training and supervision. This innovative management approach also attracts potential workers. Presented factors were confirmed by correlation analysis, ANOVA, regression and factor analysis.

Incompetent management of virtual teams lead to inefficiency and mobility of virtual workers. Proven problems are lack of opportunities, missing or unclear career path and promotion plan, impossibility to address problems and lack of supervision or help, lack of clear communication and lack of trainings.

Limitation of this paper is narrow focus on employees working in IT. On the other hand, the tests proven reliability and representativeness. Future research may explore virtual teams in other business branches and investigate team relations and its impact on reliability and retention.

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Conceptualization, L.D.; Theoretical Background, J.H.; Methodology, Software, Validation, Formal analysis, Investigation, Resources and Data curation, L.D.; Original draft preparation L.D. and J.H.; Review and editing, L.D.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Waste Analysis in the Speaker Box Assy Process to Reduce Lead Time in the Electronic Musical Instrument Industry

DOI: 10.12776/QIP.V26I3.1744

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Received: 2022-08-24 Accepted: 2022-11-16 Published: 2022-11-30

ABSTRACT

Purpose: This study aims to analyse the waste in the production line to get an efficient production lead time.

Methodology/Approach: This research uses the integration method of value stream mapping and kaizen. Based on the analysis with expert judgment, it is known that the waste comes from an inefficient factory layout. Improvements by making changes to factory layouts and merging workstations.

Findings: This research has found waste caused by ineffective factory layouts based on Focus Group Discussions (FGD). Improvements by incorporating workstations and changes to the factory layout can reduce production lead time. The results showed that the production lead time decreased from 3.21 days to 2.31 days or a decrease in the ratio of 31.15%.

Research Limitation/Implication: This research can also improve manufacturing performance such as cost efficiency, efficient layout, and labour reduction. So for similar companies, this research can be a reference for making improvements in reducing waste that can improve manufacturing performance so that they can compete in national and international markets.

Originality/Value of paper: This paper provides benefits for the musical instrument industry regarding waste reduction. According to this research, lean production can increase the productivity and quality of the production system, because it can eliminate the waste of time or the production process. The new approach of this research is used the integration methods by involving experts through FGDs to make improvements and reduce waste in the production line.

Category: Case study

Keywords: kaizen; lead time; speaker box; value stream mapping; waste

1 INTRODUCTION

Currently, the development of the manufacturing industry continues to increase. The development of this industry will lead to competition in the global market. With competition, the industry is required to make improvements in all aspects. Today, competition between manufacturing industries that have produced almost the same goods is an ongoing challenge facing the industry. One of the manufacturing industries included in the electronics sector is the musical instrument industry such as the piano. Based on the Trade Map-International Trade Center (ITC, 2019), the Indonesian musical instrument industry ranks second in the category of the most exporters. Based on the high value of exports to the global market, the market demand continues to increase (Stadnicka and Ratnayake, 2016).

The impact of increasing demand in the global market will provide a business opportunity for one the Musical Instrument Industry to develop further. It is proper for the manufacturing industry to install a strategy to win the competition with similar industries, namely to maintain the quality of the production process so that it remains effective and efficient (Nandakumar, Saleeshya and Harikumar, 2020; Baag and Sarkar, 2019).

One of the manufacturing companies located in Bekasi, Indonesia, has produced electronic musical instruments such as the main product, the piano musical instrument. This industry is a labour-intensive industry with a workforce of more than 5,000 employees. The Musical Instrument Industry is also one of the industries in which the production process from raw materials to finished products requires a fairly long process. This long period can lead to several activities that cause the production system to be not optimal. In addition, quality control that is not optimal can lead to production process activities that do not provide added value which has an impact on losses (Setiawan and Hernadewita, 2022). Based on initial observations, the production process is still found to be less than optimal. This causes the company's productivity to decrease.

Problems from the above phenomena must be corrected immediately to get an effective and efficient production process (Haviana and Hernadewita, 2019) and with the Lean Six Sigma (LSS) approach (Kurnia and Purba, 2021). Based on previous research that uses the same method to reduce waste that occurs, the Value Stream Mapping (VSM) method is used (Setiawan et al., 2021; Baby, Prasanth and Jebadurai1, 2018). The main focus of VSM is to map the production flow and information flow of a product at the total production level (Suhardi, Putri and Jauhari, 2020; Tannady et al., 2019). VSM is useful for eliminating waste and streamlining processes (Prayugo and Zhong, 2021; Ustyugová and Noskievičová, 2013; Romero and Arce, 2017). The VSM method can also be integrated with other methods such as kaizen. Kaizen focuses on continuous improvement (Hasanah et al., 2020; Garza-Reyes et al., 2017; Pech and Vaněček, 2018).

This research is supported by several relevant studies (Chowdhury, 2016; Stadnicka and Ratnayake, 2017; Setiawan, Tumanggor and Purba, 2021). Several previous studies by (Purba, Fitra and Nindiani, 2019; Setiawan et al., 2021) focused on reducing the lead time of the production process so the research only focused on eliminating waste. Therefore, this study intends to analyse more deeply identifying waste in the production line by involving experts to make improvements. In addition to involving experts, the novelty in this study will also integrate with the kaizen method. This study aims to analyse the waste in the production line to get an efficient production lead time.

2 LITERATURE REVIEW

In this section, a review of the literature related to the subject matter will be discussed. Literature is obtained through mapping according to similar research. This grouping of literature studies is focused and conceptualized based on the selected method according to the problems in the manufacturing industry.

2.1 Value Stream Mapping

Value Stream Mapping (VSM) is one of the tools used in the Lean Principle approach (Rother and Shook, 2003). The principle of Lean theory is to reduce waste, reduce inventory and operational costs, improve product quality, increase productivity and ensure comfort while working (Sukma et al., 2022). VSM can describe the condition of the process flow from suppliers to customers through various process activities. In general, this tool interprets activities that have Value Added (VA), Non-Value Added (NVA), and Necessary Non-Value Added (NNVA) (Siregar, Ariani and Tambunan, 2019). Each process flow contains Lead Time and Cycle Time. Initially, VSM was popularly used in the Manufacturing Industry to reduce waiting times during the production process. Until now VSM has been used in various industries to reduce Lead Time such as in the Service and Construction sectors industry. In addition to reducing lead time, VSM can permanently eliminate NVA activities.

2.2 Kaizen

Kaizen is a continuous improvement effort to be better than the current condition. Kaizen is also a continuous improvement that involves all employees, both upper management and lower level management (Silva et al., 2019). The main goal of Kaizen is to eliminate wastes that do not add value to the product or service from the perspective of the consumer. These wastes need to be eliminated because they cause costs that lead to reduced profits. In addition, consumers do not want to bear these unnecessary costs. Kaizen has characteristics, namely to produce products according to a schedule based on customer demand, produce in small quantities, eliminate waste, improve production flow, improve product quality and maintain 5S hygiene. Kaizen is widely applied to improve business

development because it has proven useful in many companies. Kaizen principles in increasing productivity will focus on changes that have a profit basis, such as process improvements carried out using scientific methodologies such as PDCA Cycle (Kurnia, Jaqin and Purba, 2022), DMAIC (Kurnia et al., 2021), and analysis using Pareto, 5 why analysis, cause-effect (fish-bone) and others.

3 METHODOLOGY

This study aims to shorten the lead time of the production process with a combination of VSM and Kaizen methods (Santosa and Sugarindra, 2018). This method was chosen because VSM can describe a map of the entire process and can identify non-value added. The focus of the research is on the SP Partition Board production line. The primary data used in this study is data from field observations and results from Focus Group Discussions (FGD) with expert judgment. The secondary data used is company report data such as data on the number of operators, standard time, production capacity, and others. In addition, to support this research, a literature study was also carried out to gain an understanding of research methods. This research is also carried out in steps so that this research runs in a systematic and structured manner. The flow of research from beginning to end can be seen in Figure 1.

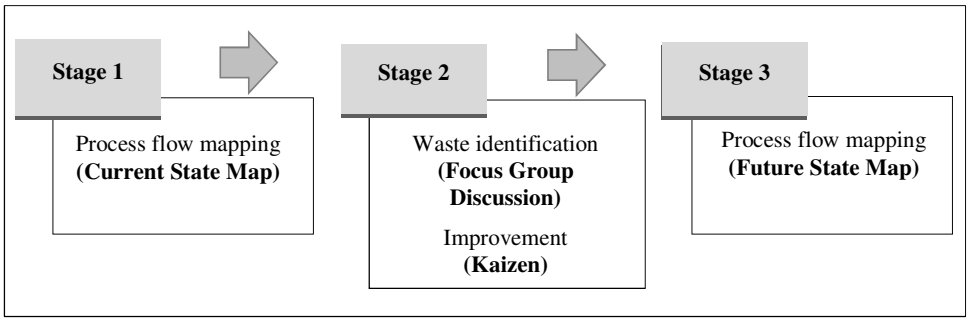

Figure 1 – Research Framework

Stage 1: The first step is mapping the Current State Map (CSM). CSM illustrates that the current production process is still not effective and efficient so the production process needs to be improved.

Stage 2: The second stage is an analysis of the causes of the problem to the long production lead time. In analysing the causes of this problem, an FGD was conducted with expert judgment. After the factors causing the problem are identified, it is continued with improvement with kaizen implementation.

Stage 3: The last step is to map the Future State Map (FSM). This map was created to describe future production processes that have been effective to be implemented. So, the new production system was successfully verified.

4 RESULT AND DISCUSSION

In this section, we will discuss data analysis from stage 1 (interpreted the problem until stage 3 (interpreted of FSM). The research implications and discussion of previous research are added in the last section. Finally, the VSM and Kaizen method is used to determine waste in the production line.

4.1 Stage 1

This research was conducted on the production line of the Speaker Box assy. The research was conducted because the lead time of this process is very long which has an impact on high production costs, long processes, and low productivity. The first step in this research is observation to find out the actual flow of the production process so that this problem is immediately corrected to get an effective and efficient production process. The production process flow of the Speaker Box is shown in Figure 2. The process of making the Speaker Box starts from the rough cutting of the Medium Density Fiberboard (MDF) material in the Running Saw Machine. The next process is the precision cutting process in Bench Saw Machine 1. After the dimensions of the material are appropriate, then the router process is carried out on the Bench Saw Machine 2. The next process is the drilling process to get the switch hole. The last process is assembly.

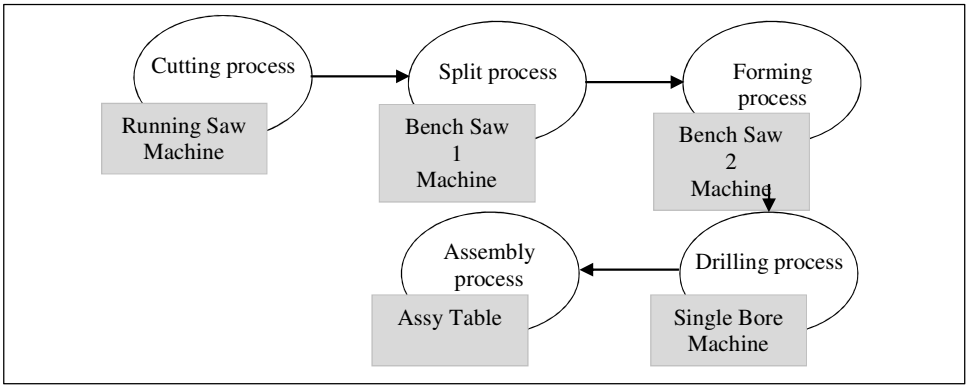

Figure 2 – Production Flow of Speaker Box Assy

The determination of the production process flow has been carried out, then the analysis begins by making VSM based on initial observations in the field. The CSM method has explained the processing time from start to finish. The CSM can be seen in Figure 3.

Based on Figure 3, it can be seen that the lead time of the Speaker Box assy manufacturing process is 3.21 days with a CT of 1,099 seconds. In this process, there are six main processes and nine operators. This process is not optimal, so it needs improvement.

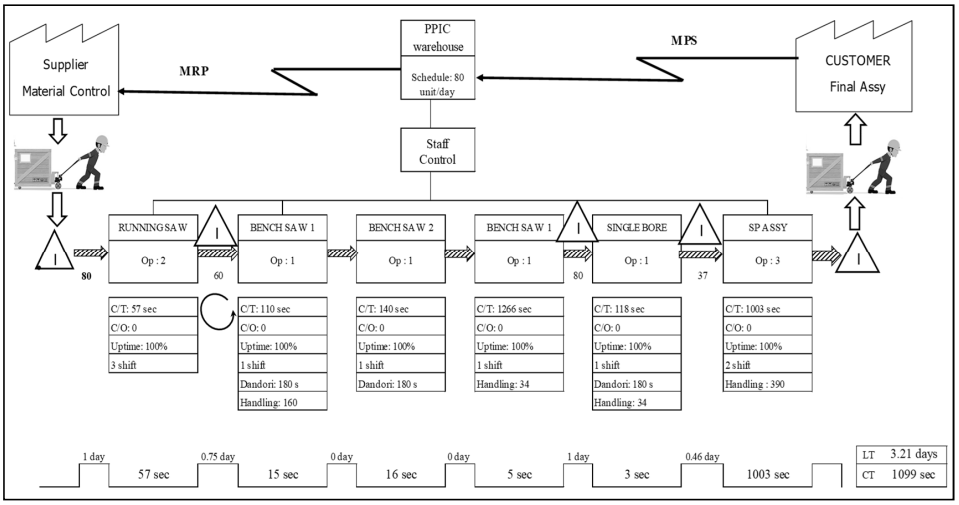

Figure 3 – Current State Map

4.2 Stage 2

After the CSM is known, the next step is to analyse the causes of the problem with the FGD. The FDG process is carried out by looking at the criteria for the team formed based on the experience of employees who are experts in the field of process improvement in reducing waste or understanding the VSM process. The FGD was conducted by the management team and five expert teams. The FGD team held an online meeting due to the Covid-19 pandemic. The analysis is carried out to find out the real cause and make improvements. Table 1 is the characteristics of expert judges who have made a decision.

Table 1 – Characteristics of Expert Judgement

Expert	Age (year)	Work experience (year)	Position	Skill	Remark
Expert 1	45	20	Board of Director	VSM Process	Internal
Expert 2	42	23	General Manager	VSM Process	External
Expert 3	47	17	General Manager	Quality, VSM process, TPM	External
Expert 4	52	18	Board of Director	Toyota Production System	External
Expert 5	47	20	Specialist	Supply Chain, VSM process, PPIC, Kaizen	Consultant

Based on Table 1, the FGD meeting was led by an internal party (expert 1) who asked external parties (experts 2, 3, and 4) how to overcome the waste of processing time in different places with the same type of industry, namely the electronic speaker box industry. During the session, the consultants also confirmed the causes and corrective actions to be taken by the production party.

As for the main critical points of analysis of the causes of problems in the FGD, it can be seen that several problems caused the lead time of the SP Box process to be long. There are three problems in the process of making SP Box, which are as follows:

1. Material process flow of many stations namely (WM01-WM03-WM09-WM10)
2. Total handling distance 618 steps
3. Very long production lead time of 3.21 days

The results of the FGD meeting have also provided recommendations for solutions to the production (internal) parties that several actions must be taken immediately.

4.2.1 Merging at workstations

Combine stations in the process of making SP Partition (WM03) with SP Box Assy (WM09). The improvements made are aimed at simplifying process control and eliminating the use of paper in the need for making a Completion Slip (CS). The combination at this workstation can be seen in Figure 4. The effect is that when the production process requires four slips/day for transactions from WM03 to WM09, now they don't use slips.

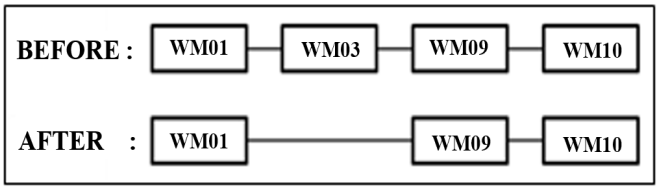

Figure 4 – Merging at Workstations

4.2.2 Merging at Single Bore Process

Combining the Single Bore process into a single process line with the Bench Saw process. The purpose of this improvement is to shorten the handling of the Bench Saw 1 engine to the Single Bore engine by 34 steps. The overall handling distance has been reduced from 618 steps to 584 steps.

4.2.3 Relayout

Factory layout change. Rearrangement at each workstation to be more effective and efficient. Changes in factory layout can be seen in Figure 5.

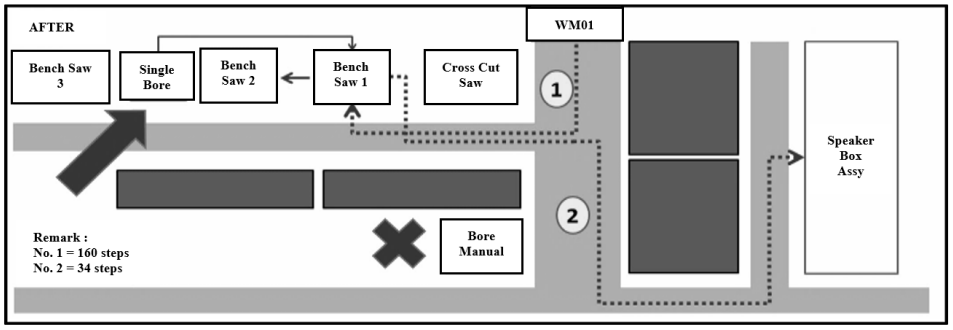

Figure 5 – Layout Production Process

4.3 Stage 3

Based on the three improvements made to the Speaker Box Assy production line, it can be seen that future processes are more effective and efficient. The production lead time of the Speaker Box Assy decreased to 2.21 days. The future production flow can be mapped and seen in Figure 6.

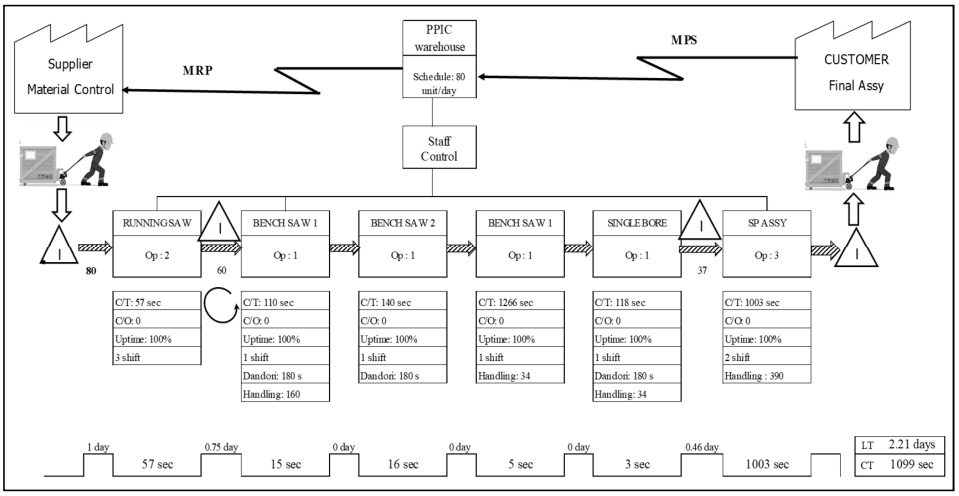

Figure 6 – Future State Map

4.4 Research Implications

Based on the improvements made to each problem factor, the production system becomes more effective and efficient. Unification of workstations and changes to factory layouts resulted in significant results in production lead time. Based on the comparison of CSM and FSM, it can be seen that the production lead time has decreased. The results of this study provide benefits for the musical instrument industry related to the reduction of waste. According to this research, lean production can increase the productivity and quality of the production system, because it can eliminate the waste of time or the production process. These upgrades can also improve manufacturing performance such as cost

efficiency, efficient layout, and labour reduction. So for similar companies, this research can be a reference for making improvements in reducing waste that can improve manufacturing performance so that they can compete in national and international markets.

4.5 Discussion

Based on the results of the analysis in the previous chapter, it can be seen that the VSM and Kaizen integration methods can reduce production lead time by 30%. This means that improvements made such as merging process stations and changing layouts have a good effect on reducing lead time. The results of this study are in line with previous research conducted by Zahoor and Kader (2019). The research found that the VSM and Kaizen methods can reduce production lead time.

5 CONCLUSION

The conclusion that the author can convey is that research has succeeded in identifying wastes that occur in the production line. This research has found waste caused by ineffective factory layouts based on FGD. Improvements by incorporating workstations and changes to the factory layout can reduce production lead time. The results showed that the production lead time decreased from 3.21 days to 2.31 days or a decrease in the ratio of 31.15%. This study has limitations on a single model. Based on the results of these studies, theoretically, it can be useful for other researchers in waste analysis studies to reduce lead time in the electronics industry. Practically this research is useful in terms of improvements by including workstations and changes in factory layout can reduce production lead times to increase the efficiency of the speaker box production process. For further research, it is recommended to make improvements by calculating Single Minute Exchange Dies (SMED) so that the production lead time in the entire model can be known.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

The Impact of Social, Economic and Gender Inequality on Prosperity in the European Union Countries

DOI: 10.12776/QIP.V26I3.1769

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Received: 2022-10-08 Accepted: 2022-11-16 Published: 2022-11-30

ABSTRACT

Purpose: This paper aims to examine the link between the three types of inequality in society and reveal the factors that contribute most to enhancing the prosperity of European Union countries and regions.

Methodology/Approach: The first part of the analysis is using correlation matrices to reveal the links between the different forms of inequality. The following parts employ Ordinary least squares models to estimate the significant factors promoting prosperity in countries.

Findings: We find a strong positive correlation between European Union countries' prosperity and gender and social equality. There is also a strong positive correlation between social and gender equality. In contrast, only a very weak negative relationship is shown between economic inequality characterised by the Gini coefficient and prosperity. It turned out, that prosperity has been shown to be strongly impacted by the population's education. However, also women's representation in top politics enhances prosperity.

Research Limitation/Implication: The scope of the analysis in terms of available data was limited, particularly when examining the determinants of prosperity at the regional level. Data for analysed variables were not available for all European Union regions.

Originality/Value of paper: The article not only focuses on a particular type of inequality but examines the relationship between economic, gender and social inequality. It offers insights into their interconnectedness, which allows a better understanding of the impact of inequality on society and a country's prosperity.

Category: Research paper

Keywords: prosperity; quality of life; social inequality; gender inequality; economic inequality

1 INTRODUCTION

Equality is one of the critical conditions essential for ensuring an efficiently functioning and prosperous economy, as it is involved in creating institutions and policies that foster innovation in societies and increase countries' economic capacity as a top priority (ECLAC, 2018).

There is ample evidence in the literature that the prosperity of countries, their economic performance, or the well-being of their populations is linked to the degree of inequality in society. As a result of persistent inequality, social cohesion is weakened (Van De Werfhorst and Salverda, 2012). In the literature, authors largely focus on examining the impact of one type of inequality on the prosperity of society. However, their results reveal the impact of different factors on the level of prosperity in a country. For example, Hanushek and Wößmann (2010) discuss the positive impact of both quality and quantity (Cooray, 2009) education on countries' economic growth. Increasing social trust (Mularska-Kucharek and Brzezunski, 2016), promoting women's representation in the labour market and reducing the gender wage gap also positively impact building a prosperous society (EIGE, 2016, 2017). On the contrary, persistent corruption in society harms the economic prosperity of countries (Gründler and Potrafke, 2019) and lowers the level of human capital (Mo, 2001). In some cases, such as income inequality, authors' opinions differ on its impact on countries' economic growth and well-being (Schneider, 2016; Mo, 2000; Shin, 2012). Based on the literature review, we can see that inequalities persist in different areas of society. Is it possible to eliminate them entirely?

Obviously, full equality cannot be achieved (Blackburn, 2008), but this does not mean that efforts should not be made to mitigate it. Therefore, exploring different forms of inequality helps to understand better the impact of inequality on society and individuals (Binelli, Loveless and Whitefield, 2015).

This is one of the reasons why we aim to analyse the impact of multiple forms of inequality on a country's prosperity. We aim to find out how economic, social, and gender inequality are interrelated and what impact the different forms of inequality have on a country's economic performance, well-being and prosperity. The factors that characterise the three main types of inequality are identified, and their impact on the national and regional level of prosperity is explored.

2 IS INEQUALITY REALLY NECESSARY?

Looking at prosperity through the lens of rising Gross Domestic Product (GDP) with unchanged levels of inequality, everyone can be positively affected by this state of affairs. Conversely, rising economic inequality leads to a widening gap between the mean and the median, i.e., between what is changing at the country level and what is happening to individuals (Stiglitz, 2012).

Easterly (2007) and several others advocate a negative relationship between inequality and economic prosperity as expressed by economic growth. From a different perspective (e.g. Barro, 2000), inequality in developing countries hinders economic growth, while in developed countries, it promotes it; but at the same time, this relationship does not explain the differences in inequality that occur over time or within countries. Castells-Quitano and Ruel (2017) advocate that if growth-promoting incentives accompany inequality, it can benefit a country's prosperity. Even, some authors argue that inequality is necessary for growth, as people with the highest incomes are perceived as job creators. However, job creation occurs across the full range of income distribution, depending on current demand. Another argument supporting inequality is the trickle-down theory, which assumes that inequality is necessary for growth and helps accumulate savings, but this argument is less present today. On the contrary, a strong argument supports the negative impact of inequality on prosperity. Namely, in countries with persistently high levels of inequality, the population does not reach its full potential, negatively affecting its future opportunities and related economic growth (Stiglitz, 2015).

The development of economic inequality may be moving in the opposite direction to other types of inequality (e.g. social, gender, ethnic, educational). It is, therefore, interesting and desirable to focus on the plurality of inequalities. The relationships between the different types of inequalities may be different. They can reinforce or undermine each other (Van De Werfhorst and Salverda, 2012). Different forms of inequality may be linked to some extent, but a decline in one type of inequality may not ensure a decline in other forms of inequality. This idea is echoed by Seguino (2005), who adds that, for example, ethnic, gender or class inequality may have different effects on prosperity since they affect the desired outcome through different pathways. The following subsections look closely at the various forms of inequalities.

2.1 Economic Inequality

Economic inequality means that economic resources are not equally distributed among individuals in a society (Paulus, 2004). It is associated with income inequality, wealth distribution, employment and human capital. If we focus on income inequality in the context of economic inequality, the latter negatively affects the well-being and political engagement of individuals and households, among which disparities are widening (Van De Werfhorst and Salverda, 2012). In societies where significant income disparities persist, we observe a higher incidence of multiple forms of adverse social outcomes that disadvantage a given group in society (Hudec and Urbančíková, 2007; Pickett and Wilkinson, 2015). Income inequality is perceived as a factor that slows down economic growth. Growing social discontent among citizens gives way to problems disrupting political stability in the country and leads to social inequalities (Ortiz and Cummins, 2011). Among other things, it increases the rigidity of economic institutions while being bound by social norms in society. Analysing the sources

of economic inequality and its possible consequences allows for a better grasp of economic and social development (Paulus, 2004). The standard and one of the most commonly used indicators of income inequality is the Gini coefficient.

2.2 Social Inequality

Social inequality is characterised as unequal distribution or access to essential material goods, which can be both material and non-material. They manifest themselves as advantages or disadvantages for those social groups affected. They are manifested not only in living conditions but also in opportunities and affect the outcomes of individuals and groups. Structural inequalities also raise the question of their inevitability. According to the authors, however, it depends on its origin. It can be eliminated if social inequality is conscious and arises from conscious action. However, the problem of its elimination is more pronounced if the inequality is part of the nature of the individual or the conditions created in the group (Hurst, Gibbon and Nurse, 2016).

Social inequalities consist of two components. The first is the social, economic or institutional processes by which certain goods are perceived as highly valuable. The second component is the rules of access and allocation of this group of goods (Suter, 2014). The determinants of social inequality are diverse, based on criteria that reflect their degree of relevance. What remains clear, however, is the division between those who lose and those who gain as a result of the persistence of this inequality. At the same time, however, these are not always the same people (Blackburn, 2008). According to Binelli, Loveless and Whitefield (2015, p.239), social inequality remains a complex and vague concept to grasp, but it is seen as "a measure of differences along a set of certain dimensions in actual achievement and expected outcomes". It is a concept consisting of multiple dimensions that are highly relevant to life in society. In addition to education and health, social inequality also includes inequality within income levels themselves. The authors have created an index that views social inequality as a concept comprising the above three separate types of inequality while being interested in actual and future outcomes. They examined social inequality in Eastern and Central European countries and found that countries with lower social inequality are politically more stable, economically more productive, and characterised by higher levels of human development. However, in other studies, social equality is mainly associated with health (e.g. Power, 1994; Dahl and Malmberg-Heimonen, 2010; Dahl, 1993) and education (e.g. Lewis, 2007; Boudon, 1974; Freitag and Schlicht, 2009; Hillmert, 2013 and others) and income inequality is considered as a part of economic inequality.

2.3 Gender Inequality

Gender inequality in the labour market and education, among other things, negatively affects countries' economic growth (OECD, 2012). Gender inequality in education seriously reduces the quality of human capital (Klasen, 2000). These

ideas are supported by the European Council, which recognises that policies promoting gender equality are essential for a country's economic growth, competitiveness and prosperity (Council of the European Union, 2006). Thus, countries whose policies promote women's equality have higher GDP per capita growth rates. At the same time, however, in countries where solid religious beliefs persist, gender stereotypes are more robust, which may translate into economic practices and consequently cause a slowdown in economic growth (Moorhouse, 2017). In countries with higher representation of women in parliament, we observe lower rates of corruption, which has been shown not only at the national (Dollar, Fisman and Gatti, 2001) but also at the regional level (Jha and Sarangi, 2018). At the same time, gender equality in the country is one of the fundamental and most important pillars of an environment that fosters innovation. Gender equality is not only a matter of ethics but also promotes economic efficiency (Ege and Ege, 2019).

Hence, gender inequality can be viewed from two perspectives, either in terms of how it changes over a person's lifetime or in terms of how it is defined by multiple domains of life, such as work, education, income, and health care (Salvini, 2014). Comprehensively, gender inequality in a country is measured through indices such as the Gender Inequality Index (GII), the Gender Equality Index (GEI), the Global Gender Gap Report (GGGR) or the Gender Development Index (GDI). At the regional level, the Female Disadvantage Index (FemDI) and the Female Achievement Index (FemAI) are available.

3 COUNTRY PROSPERITY MEASUREMENT TOOLS

GDP is used as a benchmark to measure a country's prosperity, growth or progress (Bate, 2009). GDP is a very useful indicator when measuring market output, but its use is occasionally also associated with measuring social progress and societal well-being (Eurostat, 2020). In the context of GDP, there is a discussion of the so-called Life Satisfaction Paradox since, despite the economic growth observed in developed countries, life satisfaction in these countries has not changed significantly over several decades (Badea and Pociovălişteanu, 2011).

Walker and Jackson (2019) consider that as income increases, marginal returns to income decrease, creating room for prioritising other factors in determining well-being. The failure to take non-monetary aspects into account is seen as one of the main drawbacks of measuring GDP prosperity. The most prosperous countries need not be exclusively those with the highest GDP per capita ratio. Instead, the well-being and welfare of the population should characterise the prosperity of the country (Bate, 2009). The situation of households is better reflected by other indicators than GDP per capita, focusing on measuring the consumption or income of citizens. Citizens' incomes often evolve differently from real GDP, thus offering the possibility of a different insight into citizens' well-being. Moreover, social or environmental progress does not condition economic

progress (Eurostat, 2020). To shed light on approaches to measuring prosperity and well-being, the following Table 1 provides an overview of the indicators used.

Table 1 – Prosperity and well-being Indexes (Own elaboration according to UNDP, Legatum Institute, OECD, European Commission, Eurostat)

Title	Description	Created by	Dimensions and indicators
Human Development Index	The index aims to demonstrate that the tool for assessing development should not only be economic growth but people and their capabilities.	UNDP	1. Long and healthy life (Life expectancy at birth) 2. Knowledge (Expected years of schooling, mean years of schooling) 3. A decent standard of living (GNI per capita)
Legatum Prosperity Index	The index shows the economic and social well-being of countries. It is made up of 12 pillars of prosperity that fall into one of three areas: empowering people, open economies and inclusive societies.	Legatum Institute	1. Safety & Security 2. Personal Freedom 3. Governance pillar 4. Social Capital 5. Investment Environment 6. Enterprise Conditions 7. Infrastructure & Market Access 8. Economic Quality 9. Living Conditions 10. Health 11. Education 12. Natural Environment
Better Life Index	The index aims to measure the well-being of society by tracking the development of 11 areas that are important for the population's life.	OECD	1. Housing 2. Income 3. Jobs 4. Community 5. Education 6. Environment 7. Governance 8. Health, 9. Life Satisfaction 10. Safety 11. Work-Life Balance
European Social Progress Index	The index aims to measure social progress in EU regions, complementing traditional measures of economic progress. Social progress is measured through 12 dimensions, each of which falls into one of the three areas of basic human needs, foundations of well-being and opportunity.	European Commission	1. Nutrition and basic medical care 2. Water and sanitation 3. Shelter 4. Personal security 5. Access to basic knowledge 6. Access to information and communication 7. Health and wellness 8. Environmental quality 9. Personal rights 10. Personal freedom of choice 11. Tolerance and inclusion 12. Access to advanced education

Title	Description	Created by	Dimensions and indicators
Quality of Life dimensions	The index aims to complement the results provided by the measurement of GDP as an indicator of well-being and quality of life.	Eurostat	1. Material living conditions 2. Productive or main activity 3. Health 4. Education 5. Leisure and social interactions 6. Economic security and physical safety 7. Governance and basic rights 8. Natural and living environment + overall experience of life

4 METHODOLOGY

One of the main objectives of this paper is to analyse the impact of inequality in EU countries, particularly gender diversity, on a country's prosperity. In doing so, three types of inequality will be analysed: social, economic and gender inequality. We first try to examine the relationship between different types of inequality themselves and, subsequently, between these inequalities and prosperity. Hence, we are interested in whether the different types of inequalities influence each other, the relationships between the selected types of inequalities, and how they affect the very development of prosperity in a country. The idea is supported by the work of other authors, such as Binelli, Loveless and Whitefield (2015), who also find it relevant to examine multiple types of inequality simultaneously, allowing for a better understanding of the impact of inequality on society. Van De Werfhorst and Salverda (2012) similarly emphasise the need to explore the diverse inequalities to help reveal interrelationships.

The interrelationship of these forms of inequality will be examined using correlation matrices and correlation diagrams. Gender inequality in the correlation matrix is represented by the GEI, economic inequality by the Gini coefficient of income inequality, and social inequality by the Social Progress Index (SPI). At the same time, we express well-being itself by three indicators. The first is GDP per capita, as the most widely used measure of prosperity, but with reservations; followed by the Legatum Prosperity Index (LPI), used to measure a country's prosperity (e.g., Gligorić Matić, Gavrilović, Stanišić, 2020; Kabakci Günay and Sülün, 2021; Timmerman, 2016); and the third is the Human Development Index (HDI), which assesses social progress (e.g., Grubauch, 2015; Kaur, Kaur and Soni, 2022; Ortega, 2014). The structure of the prosperity indices is quite different, they consider different spheres of life, and their results may differ.

The basic framework of the relationship between types of inequality and prosperity enables to proceed to the main research question:

Which kinds of inequalities affect higher prosperity of a country/region – economic, social or gender?

The Ordinary Least Square model (OLS) is used, with each of the three types of inequality represented by four variables. The impact of 12 variables on a country's prosperity is examined, with prosperity proxied in three different ways: a) GDP per capita, b) LPI, and c) HDI. A similar approach is applied to the NUTS II regions of the EU, giving a finer scale of perspective, while at the same time, there are no such large differences in the size of the territorial units. On the other hand, the availability of data is lower, and although the model of regions works with the same structure of effects of variables representing the three types of inequality, the number of factors is only eight. The impact of inequality factors on the GDP per capita of the regions is examined using OLS method.

4.1 Factors of Inequality Affecting the Prosperity: EU Countries

The second part further identifies the determinants that affect the level of prosperity in EU countries. In selecting indicators, we have drawn on the dimensions of several approaches to measuring prosperity outlined in the previous section. At the same time, we extended the analysed variables with the Gini coefficient, which is perceived as a standard and one of the most commonly used indicators of income inequality in countries (OECD, 2011). The indicators falling under gender inequality were drawn from Eurostat and the European Institute for Gender Equality Database. We divided the indicators of quality of life dimensions into two groups, economic and social. In selecting the variables, we relied on previous research and indices measuring a country's prosperity, progress, or well-being. Thus, we obtained factors that are considered key in promoting a country's prosperity and development.

In the group of indicators belonging to economic inequality, we include Eurostat's quality of life dimensions, where not only income indicators but also indicators of material inequality (material living conditions) are examined, and we also include the long-term unemployment rate, which has an impact on the economic well-being of the individual. Spatial inequality, which is usually expressed as regional disparities, does not enter the models (Samson et al., 2001).

The choice of indicators of social inequality is based on the literature, where social prosperity is mainly associated with a healthy population and access to education, but also security, which contributes to the prosperity of both the population and the country. The link between the need for security and crime rates and quality of life is particularly accentuated in poorer countries (Franc, Prizmic-Larsen and Lipovčan, 2012).

The last form of inequality we address in this paper is gender inequality. Surprisingly (Bjørnskov, Dreher and Fischer, 2008), well-being economists rarely include gender equality. Despite long-standing efforts to promote gender equality in EU countries, gender pay gaps are still present, and although the situation has been improving over the years, the observed progress has been plodding. A similar trend is observed in labour market participation, where, moreover, gender occupational segregation persists (Barbieri et al., 2021). The

persistent gaps may jeopardise the overall economic prosperity, as low wages act as a disincentive, which may result in a reduction of women's labour market participation but may also affect the interest in investing in further education and thus human capital development (Ciminelli, Schwellnus and Stadler, 2021). The participation of men and women in paid employment contributes to reducing poverty, increasing social inclusion and the growth of prosperity in a country (Marx, 2013). This justifies the inclusion indicators of the wage and employment gap but also the representation of women in high managerial positions as well as in politics, which helps to zoom in on the horizontal and vertical segregation in society. Table 2 lists the variables, their units of measurement and their anticipated impact on the country's prosperity.

Table 2 – List of Variables Used in the Model and Their Influence on the Dependent Variable

Variable		Abbreviation	Unit of measure	Expected impact	Source
Prosperity (dependent variable)	GDP per capita	GDP	Units of national currency per capita	X	Eurostat
	Legatum Prosperity Index	LPI	Scale 0-100	X	Legatum Institute
	Human Development Index	HDI	Scale 0-1	X	UNDP
Economic inequality (independent variables)	Gini coefficient	gini	Scale 0-100	–	Eurostat
	Inability to make ends meet	inability make ends needs	%	–	Eurostat
	Long-term unemployment	long term unemployment	%	–	Eurostat
	Inability to face unexpected financial expenses	inability unexpect expenses	%	–	Eurostat
Social inequality (independent variables)	Healthy life years	Healthy life	Years	+	Eurostat
	Early leavers from education and training	ELET	%	–	Eurostat
	Crime, violence or vandalism in the area	crime	%	–	Eurostat
	Participation rate in education and training (last 4 weeks)	edu training	%	+	Eurostat

Variable		Abbreviation	Unit of measure	Expected impact	Source
Gender inequality (independent variables)	Gender employment gap	employment gap	%	–	EIGE
	Gender pay gap in unadjusted form	pay gap	%	–	EIGE
	Women in national government	w government	%	+	Eurostat
	Women board members	w board members	%	+	EIGE

Notes: X is no impact; + is positive impact, – is negative impact.

The OLS model is used to estimate the coefficients of the linear regression equations that describe the relationship between the 12 variables representing the type of inequality and the dependent variable of EU countries' prosperity. Panel data mapping the 27 countries of the EU for the period 2011-2020 (GDP and LPI model) and 2011-2019 (HDI model) are used. To avoid possible bias in the results, the assumption of normality (Jarque-Bera normality test), model specification (Bayesian information criterion), autocorrelation (Breusch-Godfrey test) as well as heteroscedasticity (Breusch-Pagan test) were tested. Multicollinearity was tested using the variance inflation factor. The statistical significance of the model was verified using the F-test for statistical significance at the significance level $\alpha = 0.05$.

After verifying the above assumptions, we can interpret the results of the OLS method for each of three dependent variables of prosperity: a) GDP per capita (eq.1), b) LPI (eq. 2) and c) HDI (eq. 3):

$$\begin{aligned} GDP = {} & \beta_0 + \beta_1 edu\ training \\ & + \beta_2\ inability\ make\ ends\ needs \\ & + \beta_3\ inability\ unexpected\ expenses \\ & + \beta_4\ w\ government \\ & + \beta_5\ long\ term\ unemployment + \beta_6\ gini \\ & + \beta_7\ w\ board\ members + \beta_8\ pay\ gap \\ & + \beta_9\ employment\ gap + \beta_{10}\ ELET \\ & + \beta_{11}\ healthy\ life + \beta_{12}\mathrm{crime} + u_{ti} \end{aligned} \quad (1)$$

$$\begin{aligned} LPI = {} & \beta_0 + \beta_1 edu\ training \\ & + \beta_2\ inability\ make\ ends\ needs \\ & + \beta_3\ inability\ unexpected\ expenses \\ & + \beta_4\ w\ government \\ & + \beta_5\ long\ term\ unemployment + \beta_6\ gini \\ & + \beta_7\ w\ board\ members + \beta_8\ pay\ gap \\ & + \beta_9\ employment\ gap + \beta_{10}\ ELET \\ & + \beta_{11}\ healthy\ life + \beta_{12}\ crime + u_{ti} \end{aligned} \quad (2)$$

$$HDI = \beta_0 + \beta_1 edu\ training + \beta_2\ inability\ make\ ends\ needs + \beta_3\ inability\ unexpected\ expenses + \beta_4\ w\ government + \beta_5\ long\ term\ unemployment + \beta_6\ gini + \beta_7\ w\ board\ members + \beta_8\ pay\ gap + \beta_9\ employment\ gap + \beta_{10}\ ELET + \beta_{11}\ healthy\ life + \beta_{12}\text{crime} + u_{ti} \quad (3)$$

4.2 Factors of Inequality Affecting the Prosperity: EU Regions

The third part aims at investigating the factors influencing prosperity at the regional level, the number of NUTS II regions is 235. Again, the indicators are classified into three groups of inequality – economic, social and gender. The impact of the factors on prosperity in terms of GDP per capita is examined. The downside is that some data, namely on *long term unemployment*, *poverty and social exclusion*, were incomplete. We preferred to keep all regions with this limitation in the model. Table 3 lists all the indicators examined, the units of measurement, and the expected impact of these variables on countries' prosperity.

Table 3 – List of Variables Used in the Model and Their Influence on the Dependent Variable

Variable		Abbreviation	Unit of measure	Expected impact	Source
Prosperity (dependent variable)	GDP per capita	GDP	Units of national currency per capita	X	Eurostat
Economic inequality (independent variables)	Persons at risk of poverty or social exclusion	poverty soc exclusion	%	–	Eurostat
	Long-term unemployment	long term unemployment	%	–	Eurostat
Social inequality (independent variables)	Life expectancy	life expectancy	Years	+	Eurostat
	Early leavers from education and training	ELET	%	–	Eurostat
	Participation rate in education and training (last 4 weeks)	edu training	%	+	Eurostat
Gender inequality (independent variables)	Women employment	w employment	%	+	Eurostat
	Female achievement index	FemAI	Scale 0-100	+	European Commission
	Female disadvantage index	FemDI	Scale 0-100	–	European Commission

Notes: X is no impact; + is positive impact, – is negative impact.

As with the national-level models, the relevant inequality factors in relation to the prosperity of EU regions are determined using the OLS model. The regression equation has the following form (eq. 4):

$$GDP = \beta_0 + \beta_1 FemAI + \beta_2 FemDI + \beta_3 w\,employment + \beta_4 life\ expectancy + \beta_5 edu\ training + \beta_6 ELET + \beta_7 long\ term\ unemployment + \beta_8 poverty\ soc\ exclusion + u_i \quad (4)$$

5 RESULTS

The models for both EU countries and regions are tested and verified, and this section provides the results of the models with respect to the main research question, which types of inequality best explain a prosperous country or region.

5.1 The Relationship between Inequality and Prosperity and the Relationships between Different Forms of Inequality and Each Other

The relationship between the three types of inequality, social, economic and gender, is examined by correlation coefficients and illustrated by correlation diagrams. As can be seen in Figures 1 and Figure 2, there is a strong positive correlation between GDP per capita, which represents prosperity and social (0.72) and gender equality (0.70). On the contrary, the correlation between the Gini coefficient and GDP per capita is only very low (-0.21). Gender and economic inequality yield a similar result (-0.21). However, when prosperity is measured by a non-monetary indicator (prosperity index (-0.35) or development (-0.45)), a moderate negative correlation with the Gini coefficient becomes apparent.

The figures display the default GDP per capita problem for Luxembourg (small city-state) and Ireland (presence of multinationals), which spoil otherwise encouraging correlations. Countries with higher gender equality are more prosperous, and there is also a positive relationship between the SPI and prosperity. It can be concluded that GDP growth, gender equality and social development are interrelated and mutually influencing.

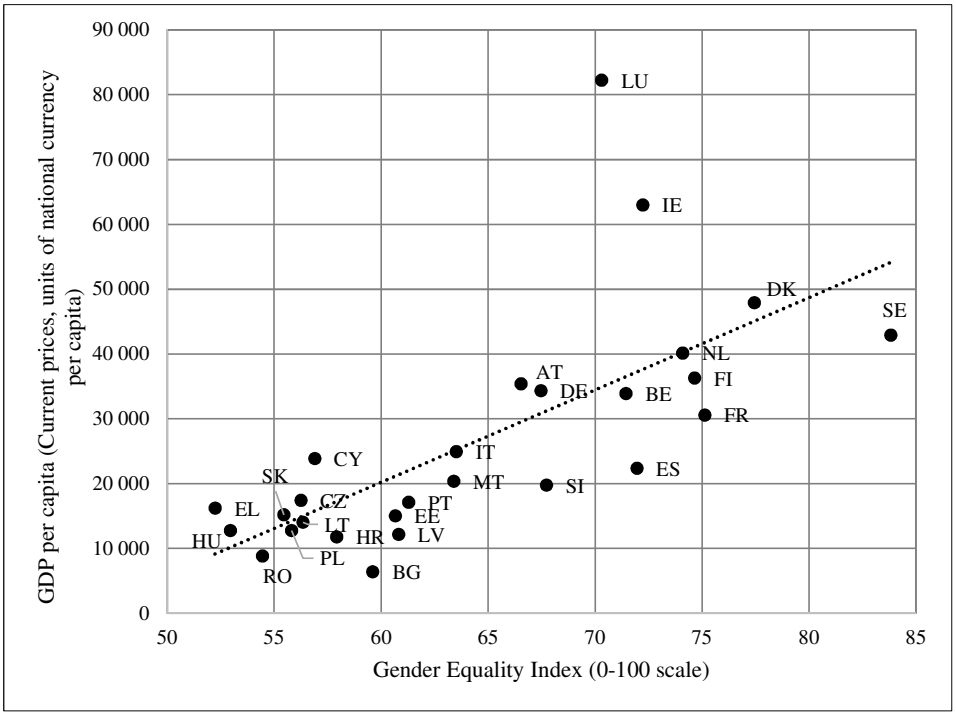

Figure 1 – GDP per Capita Vs Gender Equality Index

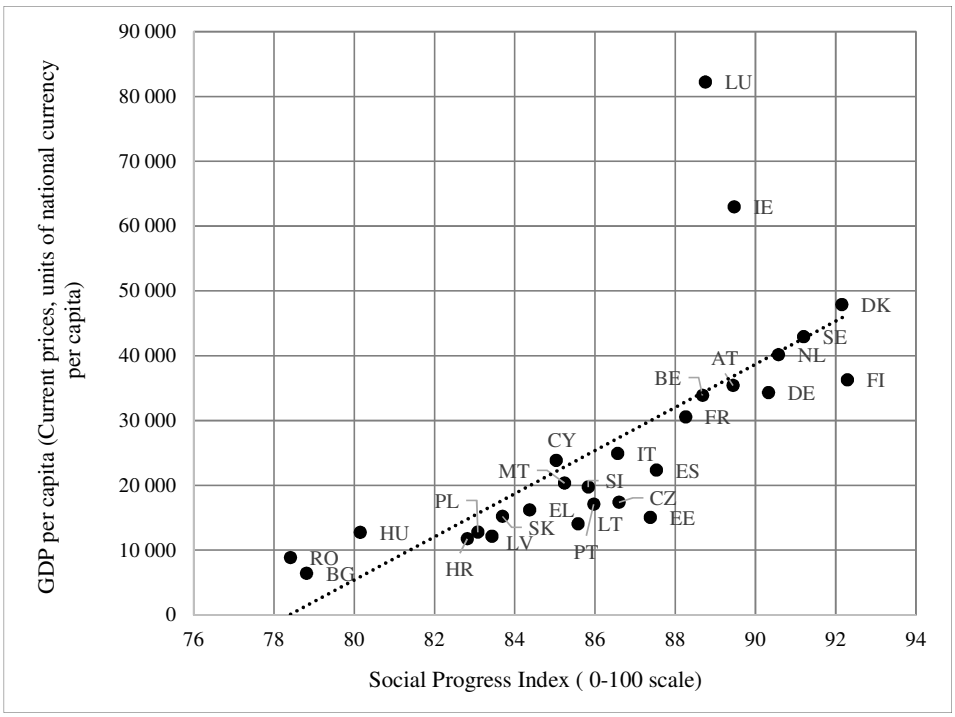

Figure 2 – GDP per Capita Vs Social Progress Index

Next, the bilateral relationships between economic, social and gender inequality are visible in the correlation matrix. As Table 4 indicates, gender inequality is strongly positively correlated with social inequality, as expressed by the SPI. However, economic inequality has a different pattern than social and gender inequality.

Table 4 – Correlation Matrix

	GEI	SPI	GINI
GEI	1		
SPI	0.81	1	
GINI	-0.21	-0.38	1

Notes: GEI – Gender Equality Index; SPI – Social Progress Index; GINI – Gini Coefficient.

5.2 The Relationship between National Prosperity and Inequality

The three OLS models have the same variables in the three groups of inequalities: economic, gender and social; they differ in the dependent variable of prosperity:

- Model 1: GDP per capita
- Model 2: LPI
- Model 3: SPI

Model 1: Due to the higher value of the inflation factor (5.53), suggesting multicollinearity, the variable *inability make ends needs* has been removed. Still, HAC correction had to be applied to solve the problem with heteroscedasticity and autocorrelation. The adjusted model did not have a normal distribution. The model with heteroscedasticity and autocorrelation problem showed six statistically significant variables, after adjusting the model, the statistically significant variable is *edu training*.

The GDP per capita of EU countries is most affected by the variable *edu training* and there is a positive relationship between education and prosperity (eq. 5):

$$\begin{aligned} GDP = \; & 32{,}567.71 + 854.3\ edu\ training \\ & - 433.07\ \ inability\ \ unexpected\ expenses \\ & + \;\; 64.65\ \ w\ government \\ & - 298.09\ long\ term\ unemployment + 21.21\ \ gini \\ & + 279.88\ \ healthy\ life \\ & - 211.78\ w\ board\ members \;\; - 705.12\ ELET \\ & - 732.47\ \ pay\ gap + \; 547.2\ crime \\ & - 347.1\ employment\ gap \end{aligned} \tag{5}$$

Model 2: Considering the LPI as the dependent variable, we solved the model's multicollinearity problem by removing the variable *inability make end needs*.

The final model did not have a normal distribution, and we removed its heteroscedasticity and autocorrelation problem by using the HAC correction. After model adjustment, three variables are statistically significant; the *edu training* variable, female representation in government and *long term unemployment*. Thus, it demonstrates that national prosperity is affected by all three forms of inequality.

Also, the factor of education (*edu training*) turned out to be the most critical and significant, however, higher women representation in government and lower *long term unemployment* contributes to greater prosperity (eq. 6):

$$\begin{aligned} LPI = {} & 67.59 + 0.32\ edu\ training \\ & - 0.10\ inability\ \ unexpected\ expenses \\ & + \ \ 0.16\ w\ government \\ & - 0.21\ long\ term\ unemployment - 0.13\ gini \\ & - 0.03\ w\ board\ members + 0.11\ \ pay\ gap \\ & - 0.01\ employmentap\ - 0.095\ ELET \\ & + 0.11932\ \ healthy\ life\ \ - 0.012\ crime \end{aligned} \tag{6}$$

Model 3: The HDI as a dependent variable of prosperity has proven to fulfil all the model requirements except for multicollinearity, heteroscedasticity and autocorrelation. Also, the Bayesian information criterion indicated the best fit of the model with ten variables. The final model did not include the variables *crime* and *inability make ends needs*. We report the final equation below (eq. 7):

$$\begin{aligned} HDI = {} & 0.80 + 1.2e^{-3}\ edu\ training \\ & - 4.85e^{-4}\ inability\ \ unexpected\ expenses \\ & + 1.46e^{-3}\ w\ government - 1.199e^{-3}\ \ gini \\ & + \ 9.46\ e^{-5}\ w\ board\ members \\ & - 5.10e^{-4}\ long\ term\ unemployment \\ & - 2.05e^{-3}\ ELET + 1.44e^{-3}\ healthy\ life \\ & + 6.55\ e^{-4}\ pay\ gap + \ 8.9e^{-4}\ employment\ gap \end{aligned} \tag{7}$$

In the third model, education (early leavers from education and training) appeared as an expected variable negatively affecting HDI. In contrast, increasing women's representation in government positively affects a country's prosperity, measured by the HDI.

5.3 Prosperity and Inequality in EU Regions

Several types of inequalities – economic, social or gender, could also explain prosperity in the territorial units of regions. However, data availability is less than adequate, and the data may not fulfil the requirements of the OLS model. Indeed, research had to be limited only to GDP per capita as a proxy of prosperity. The model did not have a normal distribution, variable FemAI showed a higher value of multicollinearity and had to be removed. The

autocorrelation problem has been removed by the Cochrane Orcutt method, and the final regression equation is (eq. 8):

$$\begin{aligned} GDP = \; & -87{,}565.25 + 1{,}084.36\, edu\ training \\ & + 1{,}440.53\, life\ expectancy - 152.95\ FemDI \\ & - 393.61\, long\ term\ unemployment \\ & - 235.56\, poverty\ soc\ exclusion - 160.26\, ELET \\ & + 6.37\, w\ employment \end{aligned} \tag{8}$$

The most significant positive impact has shown education and life expectancy, both variables belonging to the social inequality domain. At the same time, the variables *poverty soc exclusion* and *w employment* are statistically significant. In the regional model, we confirmed the impact of all forms of inequality on the countries' prosperity.

6 CONCLUSION

Countries focus primarily on their growth and development. The relationship between economic inequality and growth is still an open question. However, it is clear that too much inequality generates social problems whilst also reflecting the untapped capital of segregated groups in society. Greater levels of equality – regional, income, social and gender – are only partly in the foreground as themes worth tackling if society has sufficient resources.

Nevertheless, working to reduce inequalities and promote inclusion could ultimately contribute to the growth and development of a country or region. Therefore, this paper examines the impact of three forms of inequality in society and their impact on a country's prosperity. At the same time, it poses the innovative question of how inequalities are related across countries – whether they have similar patterns or are eventually inversely related.

There are several approaches to measuring prosperity, the most straightforward being GDP per capita, concentrating too much on economic growth and less on other aspects of prosperity. While its relation to forms of inequality is not shown to be significant, its correlation diagram indicates that the problem lies more with GDP outliers that distort an otherwise linear relationship.

OLS models have shown which factors mirroring inequality are related to the prosperity of a country or region. Income inequality correlates only weakly to gender inequality. In particular, social and gender equality share a strong relationship. If countries and regions want to achieve greater prosperity, acting on greater inequality is proving to be the right path. In doing so, the synergistic factors point to the importance of access to higher education, health care and the promotion of healthy lifestyles to achieve higher life expectancy. The models demonstrate the importance of higher representation of women in government positions and closing the pay gap, contributing to feelings of security and

participation. Whether at the national or regional level, gender equality variables are consistently significant in the models.

Perhaps the one surprising finding was that income inequality, as expressed by the Gini coefficient, was statistically insignificant for all three national models. This would suggest different paths to prosperity under different conditions of economic inequality. Hence, further research could focus on narrower groupings of countries and analyse whether the factors of prosperity in Eastern and Central European countries differ from those in Western Europe.

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Conceptualization, N.U.; Methodology, S.Š. and N.U.; Validation, N.U.; Data curation, S.Š.; Formal analysis, S.Š.; Investigation, S.Š.; Resources, S.Š.; Original draft preparation, S.Š.; Review and editing, N.U.; Visualization, S.Š.; Supervision, N.U.; Validation, N.U.; Interpretation, S.Š. and N.U.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Environmental, Social and Governance Information Disclosure Strategy of the Ten Main Spanish Listed Companies

DOI: 10.12776/QIP.V26I3.1766

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Received: 2022-10-04 Accepted: 2022-11-10 Published: 2022-11-30

ABSTRACT

Purpose: This article aims to investigate the environmental, social, and corporate governance (ESG) disclosure strategy and its impact on the financial performance of the top ten companies in terms of operating income/turnover volume.

Methodology/Approach: The study methods used include parametric correlations and logistic regression analysis focusing on data from Spanish listed companies in 2019-2020.

Findings: The findings show that IBEX35 companies need to improve web transparency in ESG reporting and a significant relationship was found between financial indicators and ESG transparency. Companies with the best positions in liquidity and return on assets rank first in non-financial indicators. Finally, it was found that the sector of the company was a significant variable.

Research Limitation/Implication: The findings of this research will help define the ESG strategy and understand the relationship between ESG and financial results. One limitation is that the information on the websites changes frequently. However, the results may contribute to being a point of reference for future studies.

Originality/Value of paper: To the best of the authors' knowledge, no previous research has been conducted to assess the ESG information disclosure strategy based on its web transparency and the financial performance of major Spanish companies.

Category: Research paper

Keywords: environmental, social and governance information; financial information; listed companies; Directive 2014/95/EU; sustainability

1 INTRODUCTION

Sustainability has been the focus of recent studies that address the relationship between business practice and commitment to sustainability in its social, environmental, and corporate governance dimensions. The European Union Directive 2014/95/EU imposed new requirements for the disclosure of non-financial information and in Spain Law 11/2018 extended this regulation by imposing the obligation of the sustainability report and its assurance from the 2019 financial year. The objective of the legal text is to favour the comparison between companies and sectors and to shuffle the financial information and not to finance it in an integrated way in order to be able to know the organizations more reliably. On the other hand, the environmental, social, and corporate governance (ESG) indicators used are aligned with the indications of the European Commission and with the Global Reporting Initiative standards, directly related to Corporate Social Responsibility (CSR) and the Sustainable Development Goals (SDG) of the 2030 Agenda in the triple dimension; environmental, social and good governance (European Commission, 2014; Warhurst, 2005; Sierra-Garcia, Garcia-Benau and Bollas-Araya, 2018; Fernández-Gago, Cabeza-García and Godos-Díez, 2020; Rajeev and Kalagnanam, 2017; Taliento, Favino and Netti, 2019; Fernández-García, 2013).

According to KPMG (2020), 98% of the Spanish companies analysed publish sustainability reports, compared to the world average of 77%, and of these, 83% referred to the SDGs in their sustainability reports, in compared to the world average of 69%. In addition, Spain has pioneered the mandatory provision of external verification of sustainability reports and, therefore, it is an interesting case study because Spanish companies obtain high scores in several sustainability indices (Sierra-Garcia, Garcia-Benau and Bollas-Araya, 2018; García-Sánchez, Aibar-Guzman and Aibar-Guzman, 2021; Gutierrez-Ponce, Arimany-Serrat and Chamizo-González, 2022).

To cover the gap of previous research, this study proposes two following objectives: first, an exploratory study of the ESG information available in the non-financial reports of 2019 and available on the websites of the IBEX35 companies is carried out; second, it investigates whether there is any significant relationship between the level of ESG transparency and its impact on the financial performance of the top ten companies in terms of operating income/turnover volume and determines whether the companies with the best ESG indicators economic efficiency are also the most transparent in ESG and to what extent these relationships explain the dependency between the two.

The exploratory study is carried out taking as a reference the set of Non-Financial Indicators (NFI) identified by the Spanish Association of Accounting and Business Administration (AECA, 2021) in its Integrated Table of Indicators and XBRLTaxonomy. AECA (2021) collects financial and non-financial information (as ESG) measured by indicators related to strategic objectives. Its objective at a financial level is to identify economic efficiency; at the

environmental level, to determine energy efficiency, emissions, and waste management efficiency; at the social level, to clearly identify human and social capital; and at the corporate governance level, to assess whether there is good corporate governance. In addition, parametric correlations and logistic regression analyses have been performed.

The results help transform the NFI that is now scattered across company websites into a more transparent and organized corpus of information, to increase stakeholder confidence. A particular finding was that IBEX35 companies need to improve the transparency of their website by presenting robust non-financial reports with ESG sustainability parameters. A significant relationship was also found between financial metrics and ESG transparency, with companies with the best positions in liquidity and ROA being the most likely to rank first in NFI. Finally, the company sector was found to be a significant variable.

2 LITERATURE REVIEW

2.1 Directive 2014/95/EU on Disclosure of Non-Financial Information

From 2018 onward, Directive 2014/95/EU requires public interest entities (PIEs) and large companies to present a non-financial report on their environmental, social and good governance practices during the previous financial year. The Directive also requires companies to describe their business model, policies, results of policies, main risks, indicators of non-financial results and, if applicable, an explanation of why they provide no information on these issues. Finally, the Directive states that companies should refer to national, EU or international regulatory frameworks to determine the information to include in the non-financial statement and specify the standard used.

An exhaustive search on the specific topic of this exploratory study revealed a lack of literature due to the novelty of the issue. The highest cluster of studies identified focused on sustainability and/or CSR. CSR emerges strongly in periods of recession (Janssen, Sen and Bhattacharya, 2015). For example, the economic crisis of 2008 revealed a change in economic cycle. “An important role in the disclosure of social and environmental information is played by financial performance, while financial leverage is a detrimental factor regarding the extent of ESG disclosure” (Campanella et al., 2020).

Previous studies determined that the problem of organizations’ lack of values and ethical principles in operations should be resolved through greater transparency in business management (Melé, Argandoña and Sanchez-Runde, 2011) and better corporate reputation (González-Ramos, Donate-Manzanares and Guadamillas-Gómez, 2014). In other words, economic sustainability depends on companies’ socially responsible behaviour, as well as on responsible consumption of resources, environmental protection, and proper management of human resources in accordance with ISO 26000 (Sitnikov and Bocean, 2013). Moure (2019)

highlights the significance of CSR communication. This literature disclose that their aims were focused on CSR, and not so often on ESG. In the same line of study, the works of Rodríguez-Cala et al. (2019) and Yusoff, Darus and Rahman (2015) have examined the potential links between corporate governance mechanisms and environmental reporting practices. Also, the investigation of Gutiérrez-Ponce, Creixans-Tenas and Arimany-Serrat (2019), analyses the quality of the web information and the Corporate Governance in the private hospitals of Andalusia and Catalonia and Gutiérrez-Ponce, Chamizo-Gonzalez and Arimany-Serrat (2022a) evaluate the web disclosure of non-financial information by the companies of four European stock market indices (IBEX35, AEX25, DAX30 and CAC40). Becht, Bolton and Roell (2003) found that "corporate governance is concerned with the resolution of collective action problems among dispersed investors".

In a globalized society, business ethics is a fundamental value and the common good they generate harmonizes with the standards for CSR established in ISO 26000 (Nunes, 2017). Based on the mentioned research (Nunes, 2017) we want to know the situation of Spanish companies regarding the accomplishment of the Directive 2014/95/EU to determine RQ1.

Some studies show that companies in emerging economies are now nearly on par with those in advanced countries in including CSR measures and policies in their business plans (Betz, 2015). The findings of Yekini et al. (2019) reveal, however, that most Chinese companies maintain an intermediate level of CSR information disclosure. The aim of NFI disclosure is to increase companies' transparency to achieve better financial and non-financial performance, more sustainable growth, and better employment, and to improve the confidence of stakeholders, particularly investors and consumers. NFI should facilitate understanding of the evolution and results of a business, and the impact of its activity. Information on corporate reputation is of great interest to investors, and CSR reports have become an integral part of the current business model (Simas, Slater and Miller, 2018). To present our RQ3 we depart from the results of Simas, Slater and Miller (2018), in our case to determine the behaviour of Spanish companies.

There is no common meaning or generally accepted definition of NFI. This lack of consensus negatively impacts efficiency of corporate communication. The literature thus proposes either changing the terminology for NFI or using specific mandatory standards for this information (Haller, Link and Groß, 2017). In line with Spanish standards, this study adopts AECA's definition of NFI (2021) and they are a reference for our research.

Normative recommendations for shareholders' general meetings include suggestions to publish reports prior to the meeting on the committee's operation, the board of directors and auditor independence. Shareholders who attend the general meeting are encouraged to exercise their rights and propose resolutions.

Recommendations for the board of directors indicate that at least 30% of board members should be women by 2020. Some previous studies have not been able,

however, to establish a clear relationship between gender diversity of the board and company performance (Redor, 2018). Other recommendations include a minimum number of annual meetings and directors' pay based on personal and company performance.

Although NFI could be readily available on the websites of large corporations, it is not commonly published in Spain (Escamilla-Solano, Plaza-Casado and Flores-Ureba, 2016).

The aim of an integrated report is to explain to financial capital providers how an organization creates value over time. Problems include the materiality of certain NFI (for example, in the supply chain) and independence at the level of external auditing. These problems present challenges for verification of NFI, which includes information on corporate reputation and information for investors (Adams, 2015).

Integrated reports could provide a reliable way to identify high quality (Churet and Eccles, 2014). For Churet and Eccles (2014), the key concept is the materiality of NFI. These authors investigate the benefits of integrated reports (financial and NFI) and the value of further analysis of data on the materiality of various environmental and social problems, specifically the significance of corporate efforts to address these problems and ways these efforts can be made visible to investors.

Several reports on corporate governance show that boards of directors should spend more time on issues related to business strategy (McKinsey Board Services, 2016). Other reports assert the tremendous importance of identifying business risks correctly, with a focus on risks due to technology and cybersecurity and argue that these risks also determine the diversity needed in the board of directors (PWC, 2018).

The academic literature indicates that good corporate governance has a positive impact on company performance leading to more predictable results and greater analyst and investor confidence (Brown and Caylor, 2006; Arjoon, 2017; Global Alliance for Banking on Values, 2016). Transparency of information on corporate governance indicators is thus vital for better business management, improved corporate reputation and generation of greater confidence (Melé, Argandoña and Sanchez-Runde, 2011; González-Ramos et al., 2014) and corporate websites are a good information channel for disseminating non-financial information and corporate transparency.

Finally, some studies on the usefulness of NFI suggest that CSR disclosure is of low quality and of limited use for financial analysts (Krasodomska and Cho, 2017). Companies are challenged to provide higher quality reports on ESG information. For this reason, this research analyses the transparency of NFI on the websites of IBEX35 companies at the beginning of the application of the regulations in Spain and to have an initial frame of reference (March 2018) for the disclosure of information ESG. The analysis of the transparency of non-

financial information on websites and anticipated compliance with the transposition of Directive 2014/95/EU to Spain and Law on Non-Financial Information is a good starting point to know how Spanish companies have prepared to elaborate sustainability reports. All this justifies carrying out this research in the first stages of transparent disclosure of ESG information and especially of those that are listed on the Stock Exchange whose information and accountability is demanded by all interest groups and by the entire society. Ultimately, this research seeks to find out if the most profitable companies listed on the Madrid Stock Exchange are also the ones that disclose the most ESG information on their websites as a key element of their efficiency and economic growth.

Based on the aims/objectives defined and literature review, the following research questions are formulated:

RQ1: What type of NFI are the IBEX35 companies disclosing before the entry Into force of the Spanish Law?

RQ2: What changes must IBEX35 companies make to adapt to the new regulations?

RQ3: Do the IBEX35 top ten companies that are more ready to report on NFI achieve a better financial position/rank:

RQ3a: In terms of Liquidity,

RQ3b: In terms of Return on Assets (ROA),

RQ3c: In terms of Return on Equity (ROE),

RQ4: Is activity sector relevant to NFI.

3 METHODOLOGY

To achieve our research aims and answer the research questions, we conducted an exploratory study. Descriptive statistics were employed alongside with correlations analysis and Predictive Models.

3.1 Data Sources

The first step was to browse the company's websites, identify and collect the information on NFI in their Integrated Table of Indicators and XBRL Taxonomy, called the Non-financial Indicators Set (SNFI). The SNFI includes three categories of NFI: 6 environmental indicators, 12 social indicators, and 9 corporate governance indicators.

Next, the 35 companies that made up the selective Spanish IBEX35 index in the month of March 2019 were identified. The companies were identified by the name of the company and the VAT number (Tax Identification Number in Spanish, or NFI). Given the number of companies in the selective IBEX35 index,

an exploratory study was made of the web disclosure of the ESG of every one of the 35 companies in the index.

3.2 Quantitative Approach

The answers to the research questions, the descriptive information and the statistics were developed using the data collected from the IBEX35 companies in the year that begins the obligation to publish environmental, social and governmental information and with the purpose to obtain a baseline analysis and evaluation of the information from future years that makes it possible to know its evolution and make comparisons.

The companies were ranked based on the number of indicators that could be calculated given the information available (not on the values of the indicators themselves). The readiness of each company for the preparation of sustainability reports was measured by the number of NFI that the company could prepare with the information found.

The available financial statements of the 35 IBEX35 companies were downloaded from SABI database (Bureau Van Dijk, 2021) and laid out in a Microsoft Excel Spreadsheet. The following data were extracted: Total Assets, Non-Current Assets, Current Assets, Equity, Current Liabilities, Non-Current Liabilities, Operations Turnover, Financial Expenses, Financial Income, EBIT and Earnings After Taxes (Net Income). Company activity sector was also included.

Based on the values obtained, the following ratios were calculated for each company: Indebtedness (Liabilities/Equity+Liabilities), Liquidity (Current Assets/Current Liabilities), Return On Assets (ROA) (EBIT/Total Assets), Return On Equity (ROE) (Net Income/Equity). The liquidity measured as stated above, ROA and ROE are widely used in the literature as key financial indicators (Flórez-Parra, Martín and Serrano, 2020) because they represent relevant values that do not usually align, such as profitability/performance and financial balance (Oladimeji and Udosen, 2019).

Once the exploratory study of the 35 IBEX35 companies had been carried out and to respond to the second objective of the research, the best ten companies were selected in terms of operating income/turnover using the predetermined search criteria in the SABI database (Bureau Van Dijk, 2021) and with the purpose of finding out if there is any significant relationship between the level of transparency of non-financial indicators and the operating result. The ratios of these companies were calculated and ordered from highest to lowest revenue volume (1 being the highest and 10 the lowest) and according to the level of transparency (number of NFI available out of a total of 27 possible general criteria included in the SNFI (Environmental 6, Social 12 and Corporate Governance 9). In addition, the ten companies were also classified according to liquidity, ROA and ROE. Debt was excluded due to lack of a clear target value to build the range. At the same time the companies were labelled as belonging

(value 1) or not belonging (value 0) to the podium in NFI, Liquidity, ROA and ROE.

Finally, the podium positions achieved simultaneously in more than one category were compared to obtain evidence to help answer the RQ3: Do the top ten IBEX35 companies most prepared to report on NFI achieve a better financial position / ranking? and a discrete variable Logit model has been used according to the research of Agyapong (2021) assessing the financial risk in small companies, Tserng et al. (2014) predicting default probability for construction firms and Wuerges and Borba (2014) detecting probability of accounting fraud.

4 RESULTS

4.1 Disclosure of Relevant NFI in IBEX35 Companies

The exploratory study of NFI on the websites of IBEX35 companies revealed scattered information that was generally difficult to access in some cases. Locating this information on the websites of the listed companies analysed required clicking on several links. In other words, although the NFI complies with international and European regulations, IBEX35 companies (Appendix) present it in separate, scattered locations on their websites. Some IBEX35 companies present outdated information, making impossible to consult all their non-financial data. Corporate governance indicators can be accessed by referring to the information available officially on the CNMV website (2015). In answering RQ2, we thus find that companies must sort, clear and update the NFI available.

In line with Gutiérrez-Ponce, Chamizo-Gonzalez and Arimany-Serrat (2021) comparison of relevant indicators on energy and water consumption and polluting emissions for all IBEX35 companies revealed that the companies' reports express the data on environmental indicators in different units of measurement. Use of different magnitudes hinders comparability. Companies must observe other companies to learn the units in which the NFI should be published (RQ2).

Relevant social indicators available for all IBEX35 companies include among others total number of employees, gender diversity and job stability (32 companies). The companies disclose information on ten social indicators. The number of employees and their training is disclosed by 100% of the companies analysed. Disclosure about employees' gender diversity and job stability exceeds 90%, information on gender diversity in senior management and employee temporality is available in more than 75% of companies. The least disclosed information is that which refers to senior management positions and net job creation that barely includes 31% of companies.

Regarding the nine corporate governance indicators, companies communicate information on every one of them. Only 11% of companies report the existence

of CSR directors and 66% reveal having an executive committee. 100% of companies disclose on their website's information on the remaining indicators of corporate governance. Gender diversity in the board and the existence of auditing committee is among those indicators informed by all the companies. Additionally, all the IBEX35 companies had different international certification standards, such as ISO 9001 (IOS, 2018a), ISO 14001 (IOS, 2019) and OHSAS 18001 (IOS, 2018b), as well as IQNet SR10 (IQNet, 2015), certifying these listed companies' CSR.

The data presented above show a general trend in the information ready to be disclosed, enabling us to answer RQ1. The information was, however, scattered on the IBEX35 companies' websites. This information could be expanded and included in a more accessible report on the website (RQ2). To rank visibility/transparency of the NFI based on availability of the data required to prepare AECA's (2021), SNFI and its interrelation with Financial Indicators, the following sections present the results obtained.

The IBEX35 companies' NFI is scattered throughout their websites. The following results were obtained by visiting the websites and exploring various links. In some cases, environmental information did not include amount or dimension. Since statements described only percentage drop in figures compared to the previous financial year, it was impossible to determine the exact amount, dimension, or quantity of these values if the figure for the previous year was not available.

Since only 43% of companies provided information on the total number of senior managers, specific data on gender diversity in senior management could not be obtained. Only 29% of the reports presented data on net job creation. As to absenteeism, some companies specified whether their figures included paternity or maternity leave, while others provided only rate of absenteeism, with no reference to number of people on leave. Results on 27 NFI are disclosed in Gutiérrez-Ponce, Chamizo-Gonzalez and Arimany-Serrat (2022b).

4.2 Strategy and Web Visibility of the ESG Information of (All) the IBEX35 Companies

The exploratory study of websites revealed an increase in employment of women and disadvantaged groups. Although all of the companies studied provided data on clients, including revenue and satisfaction, only one company in the sample mentioned ethical quality of the clients: "We will not finance operations or projects associated with companies that have been found to violate human rights".

Only one company recorded data on harassment (indicating that it had received seven reports of harassment, of which four were shelved after analysing the data and the remaining three due to lack of evidence). Almost all the reports mentioned anti-corruption and anti-fraud policies; only a small percentage of

websites did not. Companies that implemented anti-corruption measures devoted a high number of hours to training in this area. Only one company published cases of fraud and corruption (two in 2019 and none in 2020).

Nine of the 35 companies reported a percentage of female board members greater than or equal to the 30% recommended by the Good Governance Code. In the other companies, most board members were men. Further, only four companies (11.42%) had reported having CSR committees. Therefore, in relation to RQ2: What changes must IBEX35 companies make to adapt to the new regulations? The results show that IBEX35 companies need to improve and expand the ESG information on their websites: executive compensation; information technology; gender diversity among employees and senior management; environmental, social and good corporate governance issues; and investments related to the EU 2030 targets agreed at Conference Of the Parties (COP21) in Paris (United Nations, 2015) to reduce greenhouse gas emissions by 40% through sustainable investments and the most appropriate projects to achieve this goal.

Although the IBEX35 companies were ready to comply by applying the Directive 2014/95/EU at NFI level, the information published on their websites could be (RQ2) more transparent, easier to access and better organized. Further, standardization of NFI disclosure would not only enhance website transparency but also promote information on the company's reputation and provide information for investors. These results would help to create a map of the non-financial indicators of the Spanish companies on the IBEX35 stock index, and such a map would serve as a starting point to study their evolution and future improvements.

4.3 ESG Information of the Best Ten Companies in Terms of Operating Revenue/Turnover

Table 1 presents the transparency of NFI and hence the availability of the information required to prepare the SNFI for the top ten companies with the highest "Operations Return/Turnover". Analysis of the data shows that the companies disclose NFI correctly, providing information on almost all the NFI.

Specifically, 40% of the companies' websites disclosed information on nearly all six AECA NFI environmental indicators, and 60% gave information on over half of these indicators. Furthermore, 60% of the websites disclosed information on nearly all 12 AECA NFI social indicators, and 30% gave information on over half of these indicators. Only Arcelor Mittal showed poor website communication of these social indicators, with data on only four indicators (around 33%). Nearly all companies (green background) included information on the nine AECA NFI corporate governance indicators.

Table 1 – ESG Information of the Best Ten Companies in Terms of Operating Revenue/Turnover

Name	Sector	E	S	G	NFI	NFI Rank	Podium position
		6 Indicators	12 Indicators	9 Indicators	27 Indicators	S/10	
Arcelor Mittal	Industry	5 (83.3%)	4 (33.3%)	8 (88.9%)	17 (63.0%)	9	No
Banco Sabadell	Banking	3 (50.0%)	11 (91.7%)	8 (88.9%)	22 (81.5%)	2	Yes
Banco Santander	Banking	4 (66.7%)	10 (83.3%)	7 (77.8%)	21 (77.8%)	5	No
BBVA	Banking	4 (66.7%)	10 (83.3%)	8 (88.9%)	22 (81.5%)	2	Yes
Ferrovial	Industry	4 (66.7%)	10 (83.3%)	8 (88.9%)	22 (81.5%)	2	Yes
Grifols	Industry	5 (83.3%)	9 (75.0%)	7 (77.8%)	21 (77.8%)	5	No
Iberdrola	Industry	6 (100.0%)	8 (66.7%)	9 (100.0%)	23 (85.2%)	1	Yes
Inditex	Industry	5 (83.3%)	6 (50.0%)	8 (88.9%)	19 (70.4%)	8	No
Mediaset	Services	4 (66.7%)	8 (66.7%)	8 (88.9%)	20 (74.1%)	7	No
Viscofan	Industry	4 (66.7%)	9 (75.0%)	7 (77.8%)	20 (74.1%)	7	No

Notes: E – Environmental; S – Social; G – Corporate Governance; NFI – Non-Financial Indicator.

Based on overall NFI transparency/availability, we can rank the ten companies (see Table 1). The podium is composed of not three but four companies, with Iberdrola ranked highest at 85.2% NFI disclosure, and Banco Sabadell, BBVA and Ferrovial Second, at 81.5% NFI disclosure. The subsequent analysis is thus based on the financial performance of these companies and to determine how many of them are in podium positions in Financial Indicators.

4.4 Financial Indicators in the Best Ten IBEX35 Companies Selected and a Comparative Analysis

While financial and non-financial information are combined into what is known as integrated information, only certain types of companies are required to provide NFI. As seen in the exploratory study, IBEX35 companies do not have standardized NFI information, as is the case with financial information, so comparability between companies and between companies from different countries in the European environment is difficult, despite the overlap of the European Directive 2014/95/EU. Although research has a long way to go, studies

of this nature are fuelled by the current crisis of confidence, the need to understand non-financial risks, the value of companies in terms of social responsibility and NFI gaps. In this study, the ten companies with the highest operating income have been analysed and despite representing 29% of the population in this research, a bidirectional causal relationship between the disclosure of ESG information of companies and their financial results has been highlighted.

As has been said to perform the exploratory study used the SABI (Bureau Van Dijk, 2021) database. Analysis of the last available financial statements from IBEX35 companies showed that three of the top ten companies in Operations Return (30%) were banking-financial companies, while seven (70%) were from other sectors. These ten companies had safe levels of indebtedness, acceptable short-term solvency, and generally high profitability (Table 2).

Table 2 – Financial and Non-Financial Indicators (ESG), Rank and Podium of the Top Ten IBEX35 Companies in Terms of Operating Revenue/Turnover

Name	**Liquidity**	**ROA (%)**	**ROE (%)**	**NFI**
Arcelor Mittal	35.42 [3*]	1.63 [9]	10.51 [9]	16.28 [10]
Banco Sabadell	44.46 [1*]	2.40 [1*]	56.67 [4*]	62.04 [2*]
Banco Santander	58.23 [3*]	1.63 [3*]	44.80 [5]	57.26 [5]
BBVA	54.33 [2*]	1.77 [4*]	32.02 [2*]	70.11 [2*]
Ferrovial	57.54 [7]	1.46 [10]	5.40 [10]	12.72 [2*]
Grifols	28.55 [5]	1.54 [6]	14.72 [6]	20.60 [5]
Iberdrola	70.79 [8]	1.44 [2*]	55.28 [1*]	89.24 [1*]
Inditex	55.06 [9]	1.23 [5]	29.27 [3*]	65.12 [9]
Mediaset	27.83 [9]	1.23 [8]	12.60 [7]	17.47 [7]
Viscofan	20.34 [6]	1.53 [7]	13.32 [8]	16.73 [7]

Notes: ROA – Return On Assets; ROE – Return On Equity; NFI – Non-Financial Indicator.

In quest for comparability, we used the data included in Tables 1 and Table 2 to rank all the companies, as described in the methodology section. The results disclose that Iberdrola, which ranks first in transparency, also ranks first in Financial Return (ROE) and second in Economic Return (ROA), despite ranking eighth in Short-Term Solvency (Liquidity). Banco Sabadell, one of the three companies in second position, is first in ROA and Liquidity and fourth in ROE. BBVA ranks second in terms of Liquidity and ROE and fourth in ROA. Finally, Ferrovial seems to be the exception that confirms the rule. Despite ranking second in transparency, it ranks lowest in ROE and ROA and seventh in Liquidity within the cluster.

This simple tool reveals some relationships/coincidences between podium positions in NFI and financial indicators. In seeking to answer RQ3a (neither confirmed nor rejected), we observe that Banco Sabadell and BBVA rank first and second in the podium for Liquidity, meaning that 66.67% of the podium positions are occupied by companies in the NFI Podium. If we consider both ROA and the NFI Podium (RQ3b), Banco Sabadell and Iberdrola obtain first and second position, with two thirds of the podium positions corresponding to companies in the NFI podium. Finally, as to RQ3c (neither confirmed nor rejected), Iberdrola ranks first and BBVA second in the ROE Podium. Consequently, RQ3 cannot be either confirmed or rejected.

Table 3 – Spearman correlations

Rho Correlations		Liquidity	ROA (%)	ROE (%)	NFI	NFI Rank	Liquidity Rank	ROA (%) Rank	ROE (%) Rank	FInPod	Sector
Liquidity	Correlation										
	Sig. (bilateral)										
ROA (%)	Correlation	0.366									
	Sig. (bilateral)	0.298									
ROE (%)	Correlation	0.067	0.855**								
	Sig. (bilateral)	0.854	0.002								
NFI	Correlation	0.236	0.512	0.451							
	Sig. (bilateral)	0.511	0.130	0.191							
NFI Rank	Correlation	-0.236	-0.512	-0.451	-1.000**						
	Sig. (bilateral)	0.511	0.130	0.191							
Liquidity Rank	Correlation	-0.994**	-0.345	-0.067	-0.198	0.198					
	Sig. (bilateral)	0.000	0.328	0.855	0.584	0.584					
ROA (%) Rank	Correlation	-0.366	-1.000**	-.855**	-0.512	0.512	0.345				
	Sig. (bilateral)	0.298		0.002	0.130	0.130	0.328				
ROE (%) Rank	Correlation	-0.067	-0.855**	-1.000**	-0.451	0.451	0.067	0.855**			
	Sig. (bilateral)	0.854	0.002		0.191	0.191	0.855	0.002			
FInPod	Correlation	0.462	0.771**	0.771**	0.442	-0.442	-0.482	-0.771**	-0.771**		
	Sig. (bilateral)	0.179	0.009	0.009	0.201	0.201	0.159	0.009	0.009		
Sector	Correlation	-0.823**	-0.652*	-0.416	-0.417	0.417	0.811**	0.652*	0.416	-0.650*	1.000
	Sig. (bilateral)	0.003	0.041	0.232	0.231	0.231	0.004	0.041	0.232	0.042	

Notes: ** The correlation is significant at level 0.01 (bilateral); * The correlation is significant at level 0.05 (bilateral).

Evidence about the idea of (RQ3) that the most transparent companies also obtain the best financial indicators was not found. Even a Spearman correlation analysis (Table 3) did not reveal a significant association for our cluster of companies.

The Pearson correlation shows that liquidity is not related to any other variables. ROA and ROE are related both to each other and to number of positions on financial podiums; NFI and NFI Rank are related to each other but not to any financial indicator. Therefore, and to respond to answer RQ3, we ran several multivariate statistical tests, three (Models 0, 1 and 2) Ordinary Least Square (OLS) models and two (Models 3 and 4) Logit models. None of the three ordinary least squares linear regression models (Models 0 to 2) can be considered explanatory, and it could be said that the values of NFI, NFI Rank and NFI Podium cannot be explained by either the value of financial indicators (Liquidity, ROA, ROE) or the sector to which the company belongs. Therefore, to answer the RQ3: Are the top ten IBEX35 companies most prepared to report on NFI achieving a better financial position/ranking? In the following test, NFI Podium was changed to a discrete variable using a Logit model to try to explain this variable (1,0) based on the financial variable's indicators. Model 3 (Table 4) seeks to explain whether a firm rank on the NFI Podium using financial indicator values.

Table 4 – Model 3: Logit, using Observations 1-10. Dependent Variable: NFI Podium, QML Standard Errors

	Coefficient	**Std. Error**	**z**	**p-value**	
Const	−22.9441	13.9682	−1.643	0.1005	
Liquidity	10.9499	5.68069	1.928	0.0539	*
ROA	−18.6616	10.1392	−1.841	0.0657	*
ROE	15.8268	5.86280	2.700	0.0069	***
Sector	2.04827	2.16189	0.9474	0.3434	
Mean dependent var.	0.400000				
McFadden R-squared	0.420858				
Log-likelihood	−3.897692				
Schwarz criterion	19.30831				
S.D. dependent var.	0.516398				
Adjusted R-squared	-0.322071				
Akaike criterion	17.79538				
Hannan-Quinn	16.13571				
Number of cases 'correctly predicted' = 9 (90.0%) f(beta'x) at mean of independent vars. = 0.516 Likelihood ratio test: Chi-square (4) = 5.66485 [0.2256]					

Model 3 considers Liquidity, ROA and ROE as explaining the dependent variable, with a p-value less than 10% for Liquidity and ROA and less than 1% for ROE but not for sector. At the same time, the Akaike Information Criterion (AIC) for Model 3 is 17.8, so far, the best value for Models 0 to 3. One last modification in our search for the best model was to replace financial indicators (Liquidity, ROA and ROE) with presence on the podium (Liquidity Podium, ROA Podium and ROE Podium).

As Model 4 shows (Table 5), Liquidity Podium, ROA Podium and Sector seem to explain NIF Podium, with a p-value of less than 1% and an AIC of 16.3. Model 4 thus has the best fit of all models mentioned above, implying that we cannot answer RQ3 negatively. It is worth noting that Model 4 also considers sector as a key variable, answering RQ4 positively. Alternatives to Model 4 did not yield better values.

Table 5 – Model 4: Logit, using Observations 1-10. Dependent Variable: NFI Podium, QML standard errors

	Coefficient	**Std. Error**	**z**	**p-value**	
Const	31.3320	5.09902	6.145	<0.0001	***
Liquidity Podium	−32.9874	2.44949	−13.47	<0.0001	***
ROA Podium	18.5638	1.50620	12.32	<0.0001	***
Sector	−16.2153	2.00000	−8.108	<0.0001	***
Mean dependent var.	0.400000				
McFadden R-squared	0.382049				
Log-likelihood	−4.158883				
Schwarz criterion	17.52811				
S.D. dependent var.	0.516398				
Adjusted R-squared	-0.212294				
Akaike criterion	16.31777				
Hannan-Quinn	14.99003				
Number of cases 'correctly predicted' = 8 (80.0%) f(beta'x) at mean of independent vars. = 0.516 Likelihood ratio test: Chi-square (3) = 5.14247 [0.1617]					

5 DISCUSSION AND CONCLUSIONS

Directive 2014/95/EU came into force in fiscal year 2018. In Spain, the new legislation is reflected in AECA's NFI, which includes ESG information.

Our analysis highlights the need for good corporate governance in the entities mentioned in Directive 2014/95/EU. These companies drive other companies directly or indirectly related to the value chain by transmitting their corporate philosophy.

Following its proposed objectives, this descriptive and analytical exploratory study of NFI reporting by benchmark stock index companies in Spain notes that Directive 2014/95/EU has been transposed to the Spanish system over the past four years.

Despite this regulatory framework, the results of the study show that the NFI that IBEX35 companies publish on their websites is scarce and heterogeneous, which makes it difficult to access this information. In addition, some of the information is out of date. This situation limits the comparability of NFI between companies and indicates the effort that IBEX35 companies must make to achieve the homogeneity and comparability sought by the European Directive 2014/95/EU, as well as the visibility of ESG aspects in their websites. Our exploratory study, in addition to showing the disclosure of the ESG information of IBEX35 companies, has proposed to know if the IBEX35 companies with better financial indicators also report a greater number of non-financial indicator indicators on their websites at the beginning of the obligation to present ESG information for Spanish companies.

The study findings enabling us to answer RQ1, concluding that most of the IBEX companies analysed disclose ESG; 73% of these companies disclose environmental indicators, 64% social indicators and 72% corporate governance indicators, these finding are in line with those of Sierra-Garcia, Garcia-Benau and Bollas-Araya (2018) despite their data source were different of ours. This answer is reinforced by the fact that corporate governance indicators on gender diversity in the board of directors are available on websites. Also, the findings on availability of environmental information contribute to answering RQ1 but adding comparability through more homogeneous units of measurement would improve the situation (RQ2). Social information also contributes to fulfilling the regulations through the special role of diversity and job stability, reinforcing answers to RQ1 and RQ2 and most companies report corporate governance information – the lowest level is seven out of nine indicators—but we identify a clear need to improve on gender diversity (RQ2). As to integrated reporting, non-financial and financial information is available on the websites, but it is neither integrated nor access-friendly (RQ2).

The results of the study highlight the importance these companies attribute to Good Corporate Governance. This importance responds to legal and social requirements and transmits the organizations' business philosophy. More

specifically, all companies provide information on some principles of corporate governance (e.g., existence of audit committees), as such disclosure projects trust among various interest groups (stakeholders). At the same time, this study reveals significant weaknesses in good corporate governance, such as the minimal presence of women on the companies' boards of directors.

The first general conclusion to be inferred is the limited impact of regulations and laws in improving the quality of IBEX35 company websites. Although the Directive 2014/95/EU was approved in 2014, these companies still show significant margin for improvement in transparency, disclosure of information and interaction with the various users.

The IBEX35 companies could improve their website transparency to benefit stakeholders by enabling them to identify greater business value at digital level. These companies are driving forces that could promote greater website transparency in other companies not currently required by law to present NFI reports. Requiring PIEs to provide NFI could ensure strong commitment to increasing the visibility of risks related to this information and to integrating financial and non-financial information on PIE websites. With its focus on sustainable development, EU is firmly committed to disclosure of NFI and to transparency to avoid potential financial crises and obtain stronger economies.

One general conclusion drawn from this study is that making the risks derived from NFI visible and integrating financial and non-financial information on websites involves both groups and companies in a clear bid for PIEs in today's digital age. At the same time, the EU's focus on sustainable development to avoid potential financial crises and ultimately achieve stronger economies makes a firm commitment to transparent disclosure of this information.

As to RQ3, Model 4 enables us to conclude the presence of relationship/dependence between NFI Podium companies, and Liquidity and the ROA Podium. While this finding does not necessarily imply a sound relationship between ESG and Financial Indicators, it does not discount such a relationship. The company's sector (RQ4) is also relevant, as banking sector prevail over others. Companies that rank highest in Liquidity and ROA are thus more likely to rank highest in ESG. This conclusion coincides with the results obtained by Sierra-Garcia, Garcia-Benau and Bollas-Araya (2018).

To date, the companies in our cluster with the highest levels of Liquidity and ROA are also those best adapted to the Directive 2014/95/EU; their aims may focus mainly on financial performance, but UN Agenda 2030 is also a priority.

One limitation of this study is the rapidly changing in information on these entities' websites. The study considers only the website transparency of NFI available in March 2020.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

APPENDIX

	PleaseScan this QR code or follow the link: <https://docs.google.com/document/d/1I0DwPeewLkdIAbNB7Bm_C9pcLgpaOVQf/edit?usp=sharing&ouid=116260325212525882280&rtpof=true&sd=true>

Figure 1A – IBEX35 Companies

Risk Assessment Using the PFDA-FMEA Integrated Method

DOI: 10.12776/QIP.V26I3.1772

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Received: 2022-10-11 Accepted: 2022-11-11 Published: 2022-11-30

ABSTRACT

Purpose: The paper aims to introduce risk assessment in new product development as an important activity for a successful new product launch. A practical example is presented to demonstrate the integration of tools Failure Mode and Effect Analysis (FMEA) and Pythagorean Fuzzy Dimensional Analysis (PFDA) at new product development process, which is a machined component.

Methodology/Approach: Individual steps for creating a case study were carried out: create a Subject Matter Expert (SME) team, identify product failure modes, use linguistic values to assess the FMEA, compute and obtain the PFDA-FMEA and determine the product failure modes ranking.

Findings: Minimized uncertainty in the final evaluation of the FMEA and improvement in the decision-making process based on the risks already identified in the new product development process.

Research Limitation/Implication: The PFDA-FMEA method was based on the risk assessment of a machined part development process. Nevertheless, this method can be used for application in many other areas of industry that require high precision in risk analysis.

Originality/Value of paper: The aim of this paper is to reveal a new integrated method in which FMEA, Pythagorean Fuzzy Sets (PFS) and Dimensional Analysis (DA) are coherent in one model.

Category: Case study

Keywords: failure mode and effect analysis; multiple criteria decision making; pythagorean fuzzy sets; dimensional analysis; subject matter expert

1 INTRODUCTION

The rapid development of technologies that fit into the framework of Industry 4.0 bring new threats and new fails. Therefore, a new perspective is also needed on quality assurance in this context. It is particularly visible in demanding industries, which often require perfection in the smallest details and complex performances in difficult conditions, such as metalworking industry. Demands regarding the accuracy of details in the production of parts bring new challenges regarding risk assessment already during product design.

The goal of the research presented in the article is to choose a suitable method of risk analysis, applicable in the design of new components of an engineering product, based on a detailed literature survey, and to verify it on a specific solution.

The literature survey offers several methodologies to support risk analysis in different contexts, including industrial processes, product design or transport. In the publication Tixier et al. (2002), the authors identified and presented 62 different methodologies for the identification, assessment, and classification of risks. This set includes methodologies based on qualitative and quantitative approaches, as well as deterministic and probabilistic approaches. According to the authors, one of the most widely used methods is called FMEA (Failure Mode and Effects Analysis) and enables a qualitative risk analysis using scores represented by deterministic values. In the traditional version of this analysis, potential failure modes are assessed based on factors of severity, occurrence and detection using a numerical scale ranging from 1 to 10. The authors also state that FMEA is a risk analysis tool that is widely used in the manufacturing industry.

According to Yucesan, Gul and Celik (2021), an error is a failure. The author names it as a state of failure to fulfil the desired or intended goal. For a manufacturing environment, this term is defined as a part or component that causes damage to engineering equipment, manufactured products, or plant infrastructure, affects operations, production, and performance, as well as the plant's brand and reputation. Defective product is one of the main problems that manufacturing companies face. This problem does not only result in a financial loss, but it often also causes a loss of prestige (Boral et al., 2020). For companies to be able to continue operating in a healthy manner and achieve profits in today's strong competitive environment, it is necessary to increase the quality of production and reduce the number of defective products.

The risk identification process is the most important and time-consuming phase of risk analysis. Threats, probabilities of occurrence, impacts on the goals of the project or company or customer, severity of consequences, mutual links of risks are defined. The meaning of this is critical analysis, detailed investigation and evaluation or revealing activities or steps that are ineffective, reducing or increasing risk management requirements, proposing changes or corrective actions.

2 LITERARY REVIEW

Several methods can be used to evaluate potential failure modes and address their potential consequences, such as:

- Event Tree Analysis (ETA) – Analytical technique used to define potential accident sequences associated with a particular initiating event or set of initiating events (Čepin, 2011);
- Fault Tree Analysis (FTA) – An analytical technique that is used to evaluate the probability of failure, or the reliability of complex systems (Solc et al., 2021);
- Bow Tie Analysis (BTA) – Analytical technique suitable for initial risk analysis to ensure identification of high probability and high consequence events (Ferdous et al., 2012);
- 5WHY – An iterative technique used to investigate the cause-effect relationships underlying a particular problem. The primary goal of the technique is to determine the root cause of an error or problem by repeating the question "Why?". Each answer forms the basis of the next question (Nagyová et al., 2019);
- FMEA;
- An equally effective quantitative method for risk assessment is the What if? or Hazard and Operability Analysis (HAZOP) – Threat and operability analysis based on the assessment of the probability of threats and the risks arising from them (Cao et al., 2013);
- Among the frequently used qualitative methods that help to refine procedures in detailed risk analysis are, for example, SWOT analysis (Strengths and weaknesses, opportunities, and threats analysis);
- Brainstorming;
- Five Forces (5F) – Industry and risk analysis. The model works with five elements and the essence of the method is forecasting the development of the competitive situation in the industry under investigation based on an estimate of the potential behaviour of subjects and objects operating on the given market (Goyal, 2020);
- Delphi – Prognostic method of group search for a solution. Determination of expert estimate of future development or status using a group of experts (Cao et al., 2013).

2.1 Failure Mode and Effects Analysis – FMEA

FMEA was first used in the 1960s to solve problems in the aerospace and automotive industries (Bowles and Peláez, 1995). Since then, based on the original version, various improvements have been offered, which are developed

by sector – for example, FMEA for the development process, FMEA for the service sector, FMEA for production processes.

The FMEA allows to determine the impact of failures or errors on the performance of the system so that measures can be taken to reduce the risk. Each identified risk is numerically classified in the form of a Risk Priority Number (RNP). The risk number RPN is calculated by multiplying parameters severity (S), occurrence (O), detection (D) (Qin, Xi and Pedrycz, 2020). Each parameter takes values between 1 and 10 (1 indicates the lowest value and 10 indicates the highest value). Errors that lead to a high-risk number are critical and are rated as the highest priority. In the final phase, the proposal of measures to reduce the risk number is considered.

Despite the widespread use of FMEA for more than 50 years, this method still has certain limitations, which contributes to the development of new versions by combining it with other techniques (Magalhães and Lima Junior, 2021). One of these limitations lies in the use of deterministic numerical values that do not allow the quantification of uncertain or imprecise measurements inherent in the risk assessment process. According to Yucesan, Gul and Celik (2021), the limitations of FMEA primarily include the inability to deal with indeterminate failure data, subjective risk assessment according to experts, or failure to consider conditionality between individual errors. Additional weaknesses of the FMEA are presented in Tab. 1.

Table 1 – Weaknesses of FMEA

No.	Description	Literary source
1	Giving equal weight to all three factors S, O, D leads to ambiguity. The results may lead to wrong conclusions based on the RPN comparison.	Kumar et al. (2021) Qin, Xi and Pedrycz (2020) Huang et al. (2020)
2	The value from which it is necessary to implement a corrective action is not determined by a standard or another internal company directive.	Dai et al. (2011)
3	The time-consuming and financial cost of the analysis in the case of systems that are composed of many components and contain many functions, or if the analysis is used in the organization for the first time in a complex way of the system.	Boral et al. (2020) Dai et al. (2011)
4	Incorrect assessment of factors S, O, D.	Yucesan, Gul and Celik (2021) Zhang et al. (2020) Kumar et al. (2021)
5	The result of different combinations of S, O, D values for different defects leads to the same RPN.	Kumar et al. (2021) Huang et al. (2020) Liu et al. (2019)

Notes: S, O, D – Severity, Occurrence, Detection; RPN – Risk Priority Number.

Authors Magalhães and Lima Junior (2021) in their publication provide a proposal for the application of FMEA according to the three steps listed in Tab. 2.

In the first step (Step I), brainstorming is carried out and all available information is used on potential failure modes in the system, design or process that is the subject of the analysis. In this way, potential and known failure modes are identified, probable causes are discussed, and the existing means of detecting the causes and failures, if they occur, are discussed. For each identified failure mode, a score related to factors S, O, D is assigned. The last part of Step I is calculating the risk number RPN. In Step II, the values resulting from the RPN calculation for each mode of failure are sorted in descending order. The RPN classification determines the priority level of failure. Experts involved in the analysed process develop and implement action plans to eliminate or mitigate potential causes of priority failures. Finally, in the last step (Step III), the potential failure modes are re-evaluated to verify the effectiveness of the corrective actions taken.

Table 2 – Description of the Steps in the Application of FMEA

Step I	a) Specify the investigated system, design or process.
	b) Create a team of experts.
	c) Define process requirements or individual functions of product components.
	d) Identify process steps. Identify potential or known failure modes.
	e) Analyse and describe the consequences of each type of error and assess their severity.
	f) Investigate and define the probable causes of each failure mode and assess the occurrence of these causes. How often can the cause occur?
	g) Validation of existing detection methods and assessment of the ability to detect failure modes or causes through these sources. Evaluation of the most effective of the controls in the process that can detect the error or the cause of the error.
	h) Calculate the risk number (RPN).
Step II	a) Sort RPN values in descending order. Failure modes with the highest RPN values are considered the most important and will have a higher priority when determining corrective actions.
	b) Develop a corrective or preventive action plan.
Step III	a) Implement the action plan.
	b) Assess the effectiveness of corrective measures by performing a new evaluation of failure modes with respect to factors S, O, D. If the measures were effective, the value of the RPN is expected to decrease in relation to the initial state of this value.

Notes: S, O, D – Severity, Occurrence, Detection; RPN – Risk Priority Number.

The given sequence of steps of the FMEA method in Tab. 2 has been used for many years and has undergone a significant change in recent years. The automotive industry has a significant impact on people's daily lives worldwide and affects their safety (Mihaliková et al., 2021). Two basic approaches in the automotive industry represented by the AIAG manual (2022) and the VDA manual (2022) have united, and the result is a joint harmonized edition of the FMEA manual, the first edition of the AIAG & VDA FMEA Handbook.

AIAG is a global organization founded in 1982. The goal of the organization is to increase prosperity in the automotive industry by improving business processes and activities that are part of the supply chain (AIAG, 2022). VDA is an association of the automotive industry, which unites more than 620 German companies from this area and its main idea and goal is the research and production of modern, error-free and safe cars (VDA, 2022).

The methodology the AIAG & VDA FMEA Handbook provides a comprehensive guide. It is divided into seven steps for the creation of an FMEA analysis and contains changes in the form itself as well as in the evaluation tables for factors S, O, D. The handbook states the obligation to document the effectiveness of the implemented measures and perhaps the most significant change is the replacement of the risk number RPN with the evaluation factor Action Priority (AP). A seven-step approach to creating an FMEA – harmonized edition is presented in Tab. 3. This approach provides a comprehensive framework for documenting risks in a detailed and precise manner.

Table 3 – Seven-steps Approach to Creating an FMEA – Harmonized Edition

Step	**Description**
Step 1. Planning and preparation	What project?
	Team, tasks
	Identify source FMEA
	Lessons learned
	What project?
Step 2. Structure analysis	Visualize the scope of the analysis
	Process Flow Diagram
	Identification of process steps and substeps
Step 3. Function analysis	Visualization of functions
	Function tree
	Binding requirements to features
	Customer functions (both internal and external)
Step 4. Failure analysis	Creation of the chain Error - Cause and Error - Consequence
	Potential consequences of failures, failures, causes for each function of the process
	Identifying the causes of process failures
	Customer - supplier cooperation
Step 5. Risk analysis	Assigning preventive measures to the causes of failures
	Assigning detection measures to the causes of failures
	Monitoring measures

Step	Description
	Safety and legal requirements
	Assessment of importance, frequency and monitoring
Step 6. Optimization	Identification of measures necessary for risk reduction
	Determination of responsibility and deadlines for the introduction of actions
	Implementation, including confirmation of the effectiveness of measures and risk assignment after their implementation
Step 7. Documenting the results	Communication of the analysis results and the conclusions
	Complete documentation

The new approach in the harmonized Edition of FMEA guides the user to reconcile information between individual steps to ensure accuracy and completeness of the analysis. It helps identify and assign priorities to actions designed to prevent risk. It considers factors S, O, D individually, but also in combination with risk-reducing factors. The benefit of the new approach is a more intensive cooperation between the FMEA team, production plant management, customers, and suppliers.

2.2 Advanced Methods of Risk Analysis and Risk Management (MCDM methods)

To add new functions to FMEA, some studies propose a combination of decision models with existing multi-criteria decision-making methods (MCDM). According to Sarkar (2011), multicriteria decision-making is a branch of Operations Research (OR). Decision-making often involves imprecision and vagueness, which can be effectively handled using fuzzy sets and fuzzy decision-making techniques. In recent years, a considerable amount of research has been carried out on the theoretical and application aspects of MCDM and fuzzy MCDM.

According to Karunathilake et al. (2020), multi-criteria decision-making generally follows six steps, which include: (1) problem formulation, (2) requirements identification, (3) goal setting, (4) identification of various alternatives, (5) criteria development and (6) identification and application of decision-making techniques. Various mathematical techniques can be applied to this process, the choice of techniques being made based on the nature of the problem and the level of complexity assigned to the decision-making process. All methods have their pros and cons.

FMEA is considered a robust tool and is one of the most widespread techniques used to identify and assess risks (Kumar et al., 2021). It considers three risk factors at the same time, and in the industrial production sector, where the term

"risk" appears frequently, it occupies an important position, which is why the discussion of risk management in the context of FMEA is also important.

Determining and classifying potential failure modes in FMEA is a multifaceted challenge that requires decision-making based on multiple criteria – MCDM (Karunathilake et al., 2020). For this reason, FMEA can be considered a question of multi-criteria decision-making. The reason is the involvement of multiple risk factors, which includes setting priorities and evaluating potential failure modes based on the mentioned three factors S, O, D. Several studies have provided an overview of the application of multi-criteria decision-making techniques in various areas, including, but not limited to energy industry, environment and sustainability, quality management, construction and project management, safety and risk management, etc. OR achieved a relatively higher application (Sarkar, 2011; Karunathilake et al., 2020; Liu et al., 2019).

The MCDM considers the importance of risk factors, breaks down the risk assessment process into different phases and prioritizes potential failure modes through mathematical models. According to a recent literature review by Liu et al. (2019), more than 150 research papers have been published over the past two decades that report the application of multiple-criteria decision-making in the context of FMEA in different scenarios. At a broader level, common MCDM used in FMEA include, but are not limited to, winner-take-all techniques, outranking techniques, pairwise comparison techniques. In addition, various hybrid and multi-factor techniques have been developed to solve FMEA analysis.

In the issue of multi-criteria decision-making the basic components are criteria and alternatives. The various alternatives are evaluated according to established criteria to formulate a comparison of the alternatives. The results can be further improved by assigning weights to different criteria, as the importance can vary greatly between raters. Thus, there may be different levels of importance for the selected criteria from the perspective of different decision makers (Karunathilake et al., 2020). To ensure the reliability of the results, it is important to evaluate the weights assigned to each criterion by different decision makers.

The choice of a multiple-criteria decision-making technique to solve a particular problem may vary depending on the context, thus emphasizing the need to understand decision-making classifications. Multi-criteria decision-making techniques are categorized into: (1) compensatory and non-compensatory, (2) discrete and continuous, and (3) individual and group decision-making. The classification of MCDM based on discrete and continuous data is most often used. (Sabaei, Erkoyuncu and Roy, 2015)

From the point of view of discrete and continuous data, the techniques of MCDM are divided into multi-attribute decision-making (MADM) and multi-objective decision-making (MODM). MADM considers problems in an inherently discrete decision space, and MODM is based on mathematical theory and deals with problems in a continuous decision space. (Tzeng and Huang, 2014)

3 METHODOLOGY

As the machining processes market grows globally, global consumers are demanding new manufacturing technologies and product innovations. As a result, new complex processes and challenges are presented in manufacturing companies during the very development of a new product, making it necessary to overcome new and greater engineering and scientific challenges. Subsequently, however, the risk of not introducing new products to the market increases. For this reason, a risk analysis is needed in the development of a new product so that stakeholders make the right decisions and achieve the expected goals. Current risk analysis tools are not sufficient to cover identified deficiencies in the development of a new product, primarily due to the uncertainty that is present in human decisions. The proposed Pythagorean Fuzzy Dimensional Analysis – Failure Mode and Effects Analysis (PFDA-FMEA) method removes the uncertainty caused by the human factor during the risk analysis using FMEA in the new product development process.

Dimensional analysis (DA) is a technique used in the decision-making process, especially when choosing alternatives of the multi-criteria type. It is an MCDM technique that assumes that there is an optimal solution, better than others. When evaluating, DA compares each alternative with the ideal alternative to create an Index of Similarity, therefore the highest similarity index is selected as the best alternative to the MCDM multi-criteria decision-making problem. (Villa Silva et al., 2019)

Pythagorean Fuzzy Dimensional Analysis (PFDA) is applied in practice even before the FMEA is started. Its important part is the verbal assessment, based on which the results of the analysis are sorted. The advantage of PFDA is that it allows using input data both quantitatively and qualitatively, so that the information is comparable, even if the types of input data are mixed.

According to García-Aguirre et al. (2021a), the risk evaluation in PFDA compared to the conventional FMEA method is at a more advanced level, while the ambiguity of subjective human judgment is eliminated by applying Pythagorean Fuzzy Sets (PFS).

The basic concept of PFS, which are also used in the case study, is presented through the following definitions (Yager, 2013; Cao et al., 2013; García-Aguirre et al., 2021b).

Definition 1: if X represents the macroworld of considered elements, then the Pythagorean Fuzzy set P in X is given by the eq. 1:

$$P = \{\langle x, \mu_p(x),\ v_p(x)\rangle \mid x \in X\}, \tag{1}$$

where $\mu_p(x)\colon X \to [0,1]$ defines the degree of membership. Consequently, $v_p(x)\colon X \to [0,1]$ defines the degree of non-membership of element x, where $x \in X$ in P.

Definition 2: for any Pythagorean Fuzzy set $p = (\mu, v)$, p is defined as follows (eq. 2):

$$s(p) = (\mu)^2 - (v)^2, \tag{2}$$

where $s(p) \in [-1, 1]$.

According to Villa Silva et al. (2019), PFS and DA are combined into one equation in order to solve a multi-criteria decision-making problem (eq. 3):

$$PFIS_i\left(\omega_1^i, \omega_2^i, \dots, \omega_m^i\right) = \left(\prod_{k=1}^{n}\left(\mu_{\varepsilon_j^i}\right)^{T_j}, \sqrt{1 - \prod_{k=1}^{n}\left(1 - \left(v_{\varepsilon_j^i}\right)^2\right)^{T_j}}\right), \tag{3}$$

where $PFIS_i$ = Pythagorean Fuzzy Similarity Index, for $i = 1, 2, \dots, m$; ω = Pythagorean Fuzzy set; μ = assigned value of the membership function; v = assigned value of the non-member function; T_j = weight assigned to each expert, for $j = 1, 2, \dots, m, k = 1, 2, \dots, n$, a ε = macroworld of considered elements where $T_j \in [0, 1]$ and index i is defined by the Pythagorean Fuzzy set.

According to García-Aguirre et al. (2021b), the goal of the PFDA-FMEA method is to minimize uncertainty in the final evaluation of the FMEA and thus improve the decision-making process based on the risks already identified in the product design process. The method uses FMEA as a basis for collecting potential failure modes through Subject Matter Experts (SME) on the given issue, and only then is the PFDA method applied. The proposed PFDA-FMEA method is generalized in seven steps, presented in Fig. 1.

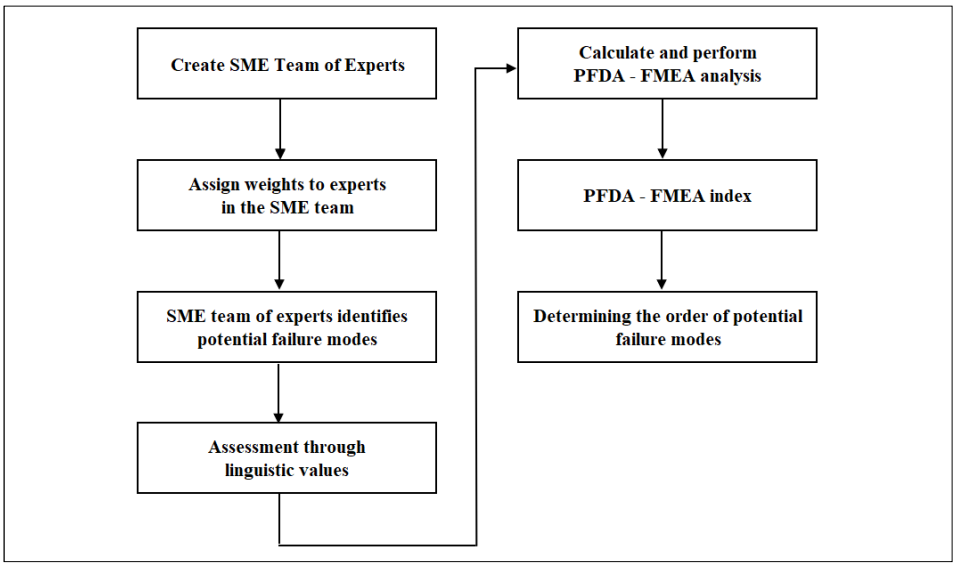

Figure 1 – Methodology of the PFDA-FMEA Approach

Step 1: Create SME team of experts on the given issue. Depending on the product/process being assessed, a group of n experts is created for the given issue.

Step 2: Assignment of weights to experts in the SME team. After the creation of the SME team, each of the experts is assigned a weight; generally: the higher the assigned value, the more important the expert's decision is for the analysis.

Step 3: The SME team of experts identifies potential failure modes and jointly determines the main internal and external characteristics that directly or indirectly affect the analysed product/ process.

Step 4: Assessment through linguistic values. Potential failure modes are evaluated by each expert independently and based on their own experience in the given field. The SME team of experts collects and defines the main areas of impact on the product/process and assigns member and non-member functions based on experience in each area of the analysed product/process.

Step 5: Calculate and perform PFDA-FMEA analysis. The results obtained in the previous step (Step 4) are used for the application of PFDA analysis according to eq. 3, subsequently using eq. 2 the values are defuzzified and the values of PFDA-FMEA analysis are obtained.

Step 6: The value of the PFDA-FMEA index is given by the mathematical calculation of the values S, O, D.

Step 7: Determining the order of potential failure modes. The results are ranked to identify the risks of potential failure modes and to support the decision to be made.

4 CASE STUDY

The company registers questions regarding the identification of risks in the design of a new component, the visualization of risks in specific areas and phases of the project, and indecision in the number and composition of interested parties who are responsible for effective risk assessment.

The proposed PFDA-FMEA method in the case study, which is based on the design of a machine part, uses FMEA analysis as the first step. FMEA helps collect and organize the main potential failure modes in the design phase of the part through the SME team of experts. The SME team of experts consists of a product designer, process engineer and quality engineer who deal with the design and development of parts for the engineering industry, managing the production preparation process and ensuring and improving the quality of production within the plant.

During the design phase of a machine part, risk analysis and assessment is required to avoid product failures and to complete the part design on time and within customer requirements. PFDA-FMEA helps to get a clear overview of the

impact of risks associated with the product design process and helps to make the right decisions about where to use what kinds of resources to avoid the potential impact of the identified risks.

Subsequently, the PFDA is applied, the purpose of which is to minimize uncertainty in human decision-making when classifying factors S, O, D.

Step 1: Creation of an SME team of experts. Tab. 3 presents a group of three experts who are labelled as SME1, SME2, SME3. SME experts analysed a machine part named *Wheel axle 022-09-005* (Fig. 2). The wheel axle is a stationary machine part that helps to transmit machine movement.

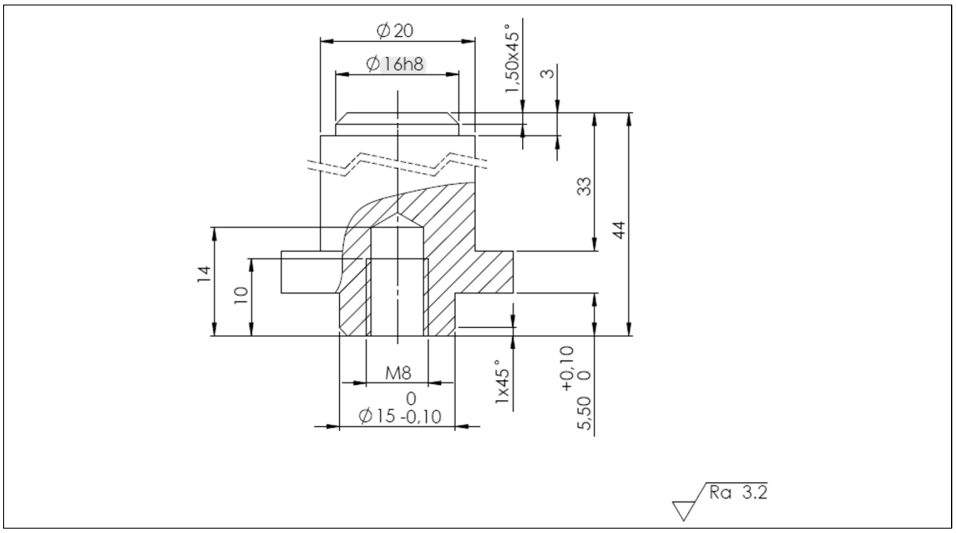

Figure 2 – Wheel Axle 022-09-005 (ICS Ice Cleaning Systems Slovakia)

Step 2: Assigning weights to experts. The weight is assigned to each expert depending on his experience and knowledge in the researched area (Tab. 4). To comply with the condition of eq. 3, that the total weight assigned to experts has a value in the range of 0 to 1, in this case study each SME expert is assigned the same weight (1/3), since the degree of expertise of each SME is in the analysed issue the same.

Table 4 – SME Team of Experts

No.	Area of Expertise	Job Title - Level of Education	Number of years of experience in the area of expertise	Weight assigned	Weight coefficient
SME1	Design of a machine part; processing of the 3D model of the part; creation of technical documentation; understanding customer requirements.	Product Designer - Bc.	4	1/3	0.33

No.	Area of Expertise	Job Title - Level of Education	Number of years of experience in the area of expertise	Weight assigned	Weight coefficient
SME2	Responsibility for the correct setting of production processes; creation of the methodology of production procedures, technical documentation and the setting of control mechanisms in order to achieve the most efficient production cycle.	Process Engineer - Ing.	5	1/3	0.33
SME3	Planning, developing, implementing, and maintaining product quality improvement and cost reduction processes; ensuring the quality of delivery of purchased parts; introduction of appropriate measurement and sampling techniques and procedures.	Quality Engineer - Ing.	8	1/3	0.33

Notes: SME – Subject Matter Experts, Bc. – Bachelor of Design in Product Design; Ing. – Master in Quality Management/ Master of Engineering.

Step 3: A team of SME experts identifies potential failure modes of the machine part. Experts in the design phase of a machine part suggest potential failure modes that have a direct or indirect impact on the part design process. For this purpose, a group of experts created and agreed on a list of 17 potential failure modes listed in Tab. 5.

Table 5 – Potential Failure Modes in the Design of a Machine Part Identified by the SME Team of Experts

Area	Potential Failure Modes (PFM) – Code	Potential Failure Modes
T	PFM1	Lack of stock of material for the start of production
Q	PFM2	Errors in the technical specification of the product
T	PFM3	The design of the product is visually unbalanced
T	PFM4	Long delivery time of raw material for production (steel)
T	PFM5	Last minute design changes
Q	PFM6	Insufficient technical performance of the product
Q	PFM7	Failure of product pilot testing
T	PFM8	Insufficient production capacity of the production plant
B	PFM9	Errors in the initial samples for the customer
B	PFM10	Outdated technology for product development
B	PFM11	Environmental burden during production not considered
I	PFM12	Lack of experts for product development

Area	Potential Failure Modes (PFM) – Code	Potential Failure Modes
Q	PFM13	Low quality of the input raw material to produce the product
I	PFM14	Changes in the customer's requirements for the final product
I	PFM15	New (untested) technologies in the production process
B	PFM16	The product exceeds the specified production costs
B	PFM17	The production plant is not ready to start production

Notes: I – innovation (a new idea, design, product or method, or development or use of a new idea, design, product or method); Q – quality (the degree to which an object or entity, e.g., process, product, or service satisfies a specified set of attributes or requirements); T – time (time period or time section), B – budget (an estimation of revenue and expenses over a specified future period of time).

Step 4: Perform FMEA using linguistic values. A team of SME used the list of linguistic values listed in Tab. 5, which include the following areas: innovation (I), quality (Q), time (T), budget (B). Each of these areas is divided into levels of influence: low (L), neutral (N), high (H), and a team of SME assigned individual values and levels their member and non-member functions.

Table 6 – Linguistic Values for PFDA, Assignment of Member and Non-Member Functions

Linguistic values and their abbreviations	Membership functions ($\mu\varepsilon$)	Non-membership functions ($\vartheta\varepsilon$)
Low Impact on Innovation (LI)	0.07	0.98
Neutral Impact on Innovation (NI)	0.47	0.49
High Impact on Innovation (HI)	0.98	0.10
Low Impact on Quality (LQ)	0.15	0.95
Neutral Impact on Quality (NQ)	0.50	0.55
High Impact Quality (HQ)	0.80	0.20
Low Impact on Time (LT)	0.35	0.85
Neutral Effect on Time (NT)	0.45	0.55
High Impact on Time (HT)	0.95	0.10
Low Budget Impact (LB)	0.20	0.75
Neutral impact on the budget (NB)	0.45	0.45
High Budget Impact (HB)	0.75	0.25

Linguistic values were subsequently used to evaluate the FMEA, which is presented in Tab. 7. The team of experts used linguistic values to define S, O and D. This step simulates the manipulation of uncertainty in the evaluation process by human judgment. For practical reasons are in Tab. 6 presented only abbreviations of linguistic values, e.g. "Low Quality Impact" (LQ).

Table 7 – Assessment of the FMEA by a Team of SME through Linguistic Values

PFM code	Severity			Occurrence			Detection		
	SME1	SME2	SME3	SME1	SME2	SME3	SME1	SME2	SME3
PFM1	HT	NT	NT	NT	NT	LT	HT	NT	NT
PFM2	NQ	NQ	LQ	NQ	NQ	LQ	HQ	NQ	NQ
PFM3	NT	LT	NT	NT	NT	LT	HT	NT	NT
PFM4	HT	NT	HT	LT	LT	NT	LT	NT	LT
PFM5	NT	HT	HT	NT	NT	NT	NT	NT	NT
PFM6	HQ	NQ	HQ	NQ	NQ	LQ	HQ	NQ	NQ
PFM7	NQ	NQ	LQ	NQ	LQ	LQ	NQ	NQ	LQ
PFM8	NT	LT	NT	LT	LT	LT	NT	LT	NT
PFM9	NB	NT	LB	NT	NT	LB	LB	LB	LB
PFM10	NB	NB	LB	NB	NB	LB	LB	LB	LB
PFM11	NB	LB	NB	LT	NB	LB	LB	NB	LB
PFM12	NI	LI	NI	LI	NI	LI	LI	NI	LI
PFM13	LQ	LQ	LQ	NQ	LQ	NQ	NQ	NQ	NQ
PFM14	HI	NI	HI	NI	NI	LI	HI	NI	NI
PFM15	LI	LI	NI	NI	NI	NI	NI	LI	LI
PFM16	LB	NB	LB	NB	LB	LB	LB	LB	NB
PFM17	HB	NB	NB	NB	NB	LB	NB	LB	NB

Notes: PFM – Potential Failure Modes; SME – Subject Matter Experts.

Step 5: Calculate and perform PFDA-FMEA. PFDA is applied through eq.3; subsequently, eq. 2 (both given in chapter Methodology) is used to defuzzify fuzzy values and obtain data. The calculation results obtained through the PFDA-FMEA are presented in Tab. 8 and include the calculation results for S, O, D.

Table 8 – PFDA-FMEA Results for Values S, O, D

PFM	Severity	Occurrence	Detection
PFM1	0.1171	-0.3157	0.1171
PFM2	-0.5260	-0.5260	0.1179
PFM3	-0.3157	-0.3157	0.1171
PFM4	0.4293	-0.4779	-0.4779
PFM5	0.4293	-0.1000	-0.1000
PFM6	0.3309	-0.5260	0.1179

PFM	Severity	Occurrence	Detection
PFM7	-0.5260	-0.7619	-0.5260
PFM8	-0.3157	-0.6000	-0.3157
PFM9	-0.2577	-0.2850	-0.5225
PFM10	-0.2292	-0.2292	-0.5225
PFM11	-0.2292	-0.3969	-0.3969
PFM12	-0.6541	-0.8765	-0.8765
PFM13	-0.8800	-0.5260	-0.0525
PFM14	0.4949	-0.6541	0.1905
PFM15	-0.8765	-0.0192	-0.8765
PFM16	-0.3969	-0.3969	-0.3969
PFM17	0.1263	-0.2292	-0.2292

Notes: PFM – Potential Failure Modes; SME – Subject Matter Experts.

An example of calculating the S value for line number 1 in Tab. 8. The values used in the calculation are based on the values in Tab. 9.

Table 9 – Numerical Values of PFM 1 Used in the PFDA-FMEA

PFM1	Severity			Occurrence			Detection		
	HT	NT	NT	NT	NT	LT	HT	NT	NT
$(\mu\varepsilon)$	0.95	0.45	0.45	0.45	0.45	0.35	0.95	0.45	0.45
$(\vartheta\varepsilon)$	0.10	0.55	0.55	0.55	0.55	0.85	0.10	0.55	0.55

Notes: PFM – Potential Failure Modes; HT – High Impact on Time; NT – Neutral Effect on Time; LT – Low Impact on Time.

For calculating membership values $(\mu\varepsilon)$ for S – severity, the first part of eq. 3 was used:

$$PFIS_3 = (0.95)^{\frac{1}{3}} \cdot (0.45)^{\frac{1}{3}} \cdot (0.45)^{\frac{1}{3}} = 0.5773. \tag{4}$$

For calculating non-membership values $(\vartheta\varepsilon)$, the second part of eq. 3 was used:

$$PFIS_3 = \sqrt{1 - \left\{[1-(0.10)^2]^{\frac{1}{3}} \cdot [1-(0.55)^2]^{\frac{1}{3}} \cdot [1-(0.55)^2]^{\frac{1}{3}}\right\}} = \sqrt{1 - \left[(1-0.01)^{\frac{1}{3}} \cdot (1-0.3025)^{\frac{1}{3}} \cdot (1-0.3025)^{\frac{1}{3}}\right]} = \sqrt{1-(0.7839)} = 0.4649. \tag{5}$$

To defuzzify the values, eq. 2 was used:

$$s(p) = (0.5773)^2 - (0.4649)^2 = 0.1171 \quad (6)$$

Step 6: PFDA-FMEA index. Values listed in Tab. 7 were used to calculate the PFDA-FMEA Index (S×O×D). The results are presented in Tab. 9 and potential failure modes are listed according to the value of the risk number.

Table 10 – PFDA-FMEA Results and Risk Assessment

Potential Failure Modes (PFM) – code	**PFDA-FMEA Index**	**PFDA-FMEA ranking according to the value of the risk number**
PFM1	-0.0043	6
PFM2	0.0326	2
PFM3	0.0117	3
PFM4	**0.0980**	**1**
PFM5	0.0043	5
PFM6	-0.0205	8
PFM7	-0.2108	16
PFM8	-0.0598	13
PFM9	-0.0384	12
PFM10	-0.0275	10
PFM11	-0.0361	11
PFM12	-0.5026	17
PFM13	-0.0243	9
PFM14	-0.0617	14
PFM15	-0.0148	7
PFM16	-0.0625	15
PFM17	0.0066	4

Step 7: Determine the ranking of potential failure modes. The results are sorted to identify those potential failure modes for which action needs to be taken. This assessment of potential failure modes reveals the future scenario to be considered when assessing risk in the design of a machine component. In this sense, PFM4 – Long delivery time of raw material for production (steel) represents the greatest risk because it has the highest index number.

It is evident from the PFDA-FMEA ranking of potential failure modes listed in Tab. 10 that the lowest number represents the PFM with the highest risk.

5 DISCUSSION AND CONCLUSION

FMEA is an advanced tool that can be defined as simple and intuitive providing added value to the risk management process (Juhaszova, 2013). Based on the literature survey in the introduction chapter, it can be concluded that the application of FMEA in risk assessment is criticized by the professional public mainly because of the uncertainty present in risk classification. According to Turisova and Kadarova (2015), the FMEA method is usually developed by a team of experts. Analysis means team responsibility, where individual problems arising are solved by consensus, i.e. that the opinion of the most active members is accepted.

In the case study, the proposed PFDA-FMEA method has the advantage over the conventional FMEA that it compensates the possible uncertainty with linguistic values and their influence levels. Although there are currently various approaches proposed to improve FMEA, for example the harmonized edition of AIAG & VDA FMEA (Česká společnost pro jakost, 2019) focused not on the product of factors S, O, D but on the priority for action especially from the point of view of the severity of the impacts on the production plant, customer or final consumer. Unlike the conventional FMEA method, the proposed PFDA-FMEA method combines PFS, dimensional analysis and FMEA itself, thereby improving the current FMEA methodology.

Risk identification is the process of finding, recognizing, and describing risks. Risk analysis is a process to understand the nature of risk and to determine the level of risk, that is – the magnitude of a risk or combination of risks expressed in terms of the combination of consequences and their likelihood (Lengyel, Zgodavová and Bober, 2012). Fig. 3 shows the current state of risk assessment in the design of a machine component in company ICS ICE Cleaning Systems, which is complexly organized and risk identification in this case is quite difficult. In comparison with the proposed state, which results from the case study, it is clear how it is possible to proceed in the future in the identification of potential failures modes and which areas can be affected or are the most critical.

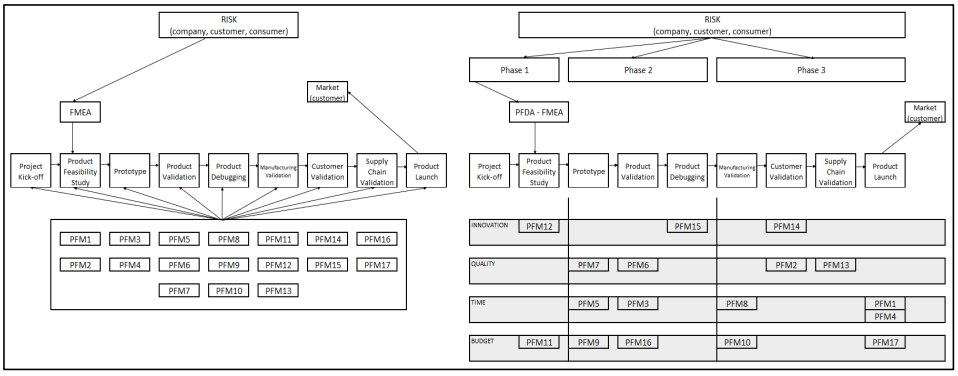

Figure 3 – Comparison: Risk Assessment Before and After the Introduction of PFDA-FMEA in the Company

This visualization makes it possible to assign resources to those areas where they are needed to mitigate the identified risks. Areas (quality, innovation, time, budget) help classify the goals to be achieved.

Fig. 4 shows a comparison of potential failure modes against the values for severity, occurrence and detection, where it is clear that PFM4, PFM5, PFM6 and PFM14 had the highest values for the severity of impacts.

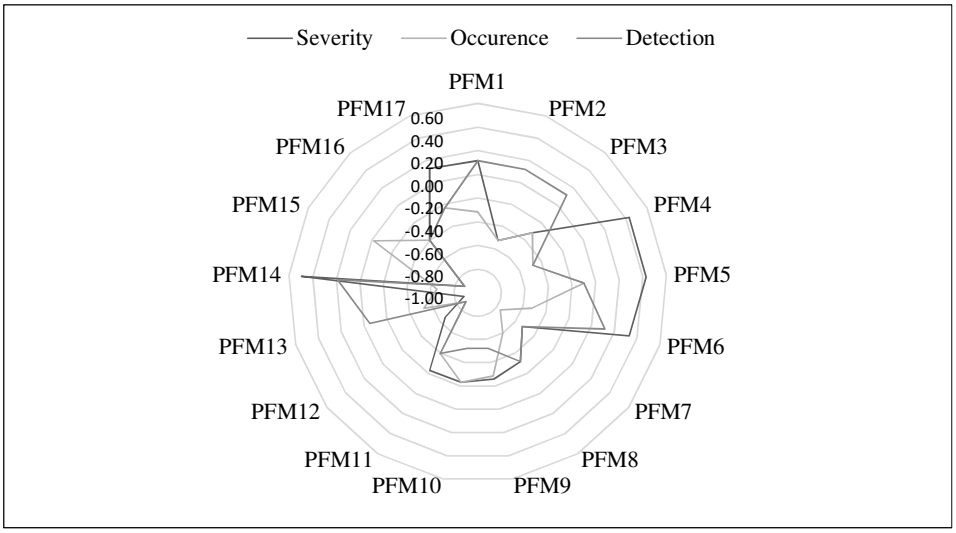

Figure 4 – Comparison: PFM and Values of PFDA-FMEA for S, O, D

After reviewing the literature there is room for improvement in the topic of risk analysis in the new product design process, but the presented integrated PFDA-FMEA method overcomes the main identified shortcomings and provides an advanced solution for risk assessment methods. The main benefits of the method include:

1. Elimination of uncertainty in human judgment in risk assessment due to the diversity of opinions and views in the cross-sectional team;
2. Determining the sequence of risks (allows to focus on resources at the right time in the right area);
3. A visual way of identifying risks (allows to focus on the area where the risk may occur);
4. Possible implementation of the method in various areas of industry (nanotechnology, medicine, ...) where high precision in risk assessment is required.

ACKNOWLEDGMENTS

This research was funded by the Ministry of Education, Science, Research and Sport of the Slovak Republic, Grant No. VEGA 1/0633/20 Research of the variability of properties and functions of products made of composite materials produced by additive manufacturing.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Design of Industrial System Using Digital Numerical Control

DOI: 10.12776/QIP.V26I3.1747

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Received: 2022-08-28 Accepted: 2022-11-10 Published: 2022-11-30

ABSTRACT

Purpose: This paper would be based on applying quality 4.0 technology to mechanical factories. The overall purpose of quality 4.0 technology is to transition production lines from semi-automatic production to automatic production.

Methodology/Approach: The lean six-sigma with five phases of Define Measure Analysis Improve Control (DMAIC) would be used to measure the quality of 4.0 integration. Each phase is composed of statistical tools, hypothesis testing, experimental design, industrial tools, etc. to provide less error for precision in manufacturing control.

Findings: Results shows that scrap products decreased by 59.66% per year, the productivity of the production line assembly increased by 7.8%, and the total lead time decreased by 20 minutes. As well as the required payments and the monthly reduction of value cost of 500 USD for jig improvement, and profit is 678 USD per month and 7,636 USD per year.

Research Limitation/Implication: Gaseous hydrocarbons or organic compounds from n-hexane can be a challenge for sensors utilizing signals for researchers. Also, another issue would be the power supply output to the sensor due to external interference.

Originality/Value of paper: This research focuses on applying the usage of sensors from a semi-automatic machine tool to an automatic machine tool.

Category: Case study

Keywords: sensor; signal processing; DMAIC; computer vision; digital numerical control

1 INTRODUCTION

Due to the advancement of precision in mechanical products from the well-known machinery industry in China, Taiwan, Korea, India, and Malaysia has caused Japanese manufacturers to lag behind (Rehman et al., 2018). Quality systems such as ISO 9001:2015 or IATF16949:2015 have been used to improve product quality and production lines which means Japan must apply quality systems in their companies to catch up with the other global manufacturing countries (Gandhi, Sachdeva and Gupta, 2019). Lean Six Sigma is an indispensable technique for manufacturing businesses and has been used in continuous improvement for over 20 years (Garg, Raina and Sharma, 2020; Prabu et al., 2013). The phases of DMAIC in Lean Six Sigma engineering deal with the entire job (Ahmed, 2019; Gupta et al., 2018) and follow the PDCA (Plan-Do-Check-Action) cycle planning. The process of machining mechanical parts always generates abnormal errors in no one direction, it is essential to ensure stable process parameters throughout the machining time (Jamil et al., 2020; Bedi et al., 2015; Karout and Awasthi, 2017). Controlling, limiting or eliminating process variation, improving production productivity, minimizing waste, and eliminating waste is all that is needed to apply DMAIC to operations. continuous improvement activities (Soundararajan and Janardhan, 2019; Alqahtani, 2020).

Applying DMAIC to continuous improvement, providing a systematic view of supply chain operations, strategic planners see problems visually and make decisions easily Specifically. Product quality improvement (Smetkowska and Mrugalska, 2018), machining process quality improvement, and human capacity improvement are essential activities in the continuous improvement process. The continuous improvement method keeps the process perfect and supports the previous and subsequent processes in the best way (Kaoudom Yimtrakarn and Choomrit, 2019; Kaushik and Khanduja, 2009; Kumar, Wolfe and Wolfe, 2008). Previous studies have shown that applying Lean Six Sigma techniques promotes growth in production, motivating people to better understand the quality management system from theory to practice (Marques and Matthé, 2017; Mustaniroh, Widyanantyas and Kamal, 2021; Nandakumar, Saleeshya and Harikumar, 2020; Padmarajan and Selvaraj, 2021). Improve process efficiency, improve productivity, improve product quality stability throughout the machining process, making the company improve its competitive position compared to other companies (Basios and Loucopoulos, 2017). Managers must always be interested in continuous improvement activities, and closely monitor the operation process. The DMAIC phases help managers clearly identify problem points, areas that need to be faced and make improvements, following a specific plan (Barbosa, de Carvalho and de Souza, 2014; Biju and Nair, 2017). Improving customer satisfaction, reducing quality costs, and reducing machining costs are thoroughly solved by Lean six sigma tools. Lean tools eliminate waste and defects that arise in the machining line.

The DMAIC phases carry out continuous improvement activities in the manufacturing process, to process optimization, defect elimination, waste elimination, and multiple benefits (Carnovale et al., 2016). Value chain diagram. Pareto charts and overall yield are used during the DMAIC phase analysis of problem points. SIPOC (Supplier-Input-Process-Output-Customers) cycles, fishbone diagrams and other diagrams are applied for cause analysis (Cunha and Dominguez, 2015; De Mast and Lokkerbol, 2012). Machining process throughput performance is represented on a process capability measure and developed by statistical tools for quality control, DMAIC provides quick and timely analytical tools, Fast implementation of process improvement. DMAIC is methodologically limited and weak in the technical aspects of data aggregation. There are no studies that combine Lean Six Sigma techniques with digital control techniques into digital twin in machining operations, facial recognition computer vision techniques into operator behavior control and measurement systems (digital twin) sets the quality of the product.

Product quality depends on the workmanship of the processor, it is necessary to have a strict control plan. Improving product quality means gradually eliminating human skills in production activities (Rifqi et al., 2021; Kosina, 2015). Optimize tooling in the production process, eliminating the dependency on human skills (Pereira et at., 2019; Pech et al., 2018). In this study, re-design measuring instruments, set up measuring systems at each processing stage, collect product quality measurement data automatically, analyse product quality data one by one following a systematic way. The company's management is constantly monitoring the quality improvement work of the Bush product line, a linear guide for a ball that rotates around a cylinder, with extremely low friction and precise movement, the ball bearing system is designed with a material with a low coefficient of friction.

The benefits of this study are as follows: (1) Integrating statistical tools, experimental design, industrial tools into Lean six sigma techniques in continuous improvement activities; (2) Computer vision recognizes human faces to control machine operator behaviour; (3) Computer Integrated Manufacturing (CIM) into automation calling machining programs, eliminating the dependency on worker skills; (4)Sensors used in continuous improvement activities to improve production line productivity, eliminate waste, control waste; (5) Product quality measurement system implemented at each processing stage, overall quality management; (6) Create a close connection from the research and academic environment to the actual outsourcing environment. remove barriers in people's thinking and practice.

In this study, we propose to apply Digital Numerical Control (DNC) technique to call machining machines automatically. Computer Vision technology to recognize human faces to control the position of each employee. Online product quality measurement system at each stage according to total quality management rules, redesigned hole grinding tool with the used of sensors. The paper is organized as follows: Part II presents the raw material and research methodology,

Part III presents the results of the case study and discussion, Part IV records the conclusions and research direction.

2 RAW MATERIALS AND RESEARCH METHODOLOGY

Lean Six Sigma consists of 5 phases (De Mast and Lokkerbol, 2012) such as DMAIC. Phase 1 (Define) shows the content of the problem points. Phase 2 (Measure) measures problems arising in the topic to be researched, sets goals according to SMART criteria, and makes action plans. Phase 3 (Analysis) clearly and specifically analyses the content of the problems using statistical methods or tools such as hypothesis testing, QC tools, six sigma tools, industrial tools (Khayrullina, Kislitsyna and Chuvaev, 2015). At each stage, identifying waste points is a necessary requirement. However, the limitation that needs attention is the analysis and measurement of inappropriate factors such as incorrect application of analytical tools, sample analysis is not suitable, this leads to incorrect measurement analysis results. Analysis and measurement of the stage are done in real-time, so the problem is detected wrong leading to the wrong requirements, generating waste products, leading to additional costs in the process of implementing improvements. Phase 4 (Improve) establishes improvement action to eliminate wastes or arising causes just found from phase 3 (Analysis) and implements improvement action in the real environment. Phase 5 (Control) collects data from the results of applying improvement measures using statistical tools such as hypothesis testing, control charts or histograms, as well as process capability assessment.

2.1 Define

The Pareto chart and the pie chart analyse the product line quality data for the past 1 year, and select the objects that need to be improved and increased the productivity of the machining line. The Bayesian formula is used to determine the type of processing line that gives rise to defective products (eq. 1):

$$P(B_i|A) = \frac{P(B_i)\times P(A|B_i)}{\sum_{j=l}^{m} P(B_j)\times P\left(A\middle|B_j\right)}, i = l, \dots, m. \tag{1}$$

Cycle time, lead time, valid time and non-value time on the machining line recorded by value stream mapping.

2.2 Measure

The Bootstrap ANOVA technique in the single variance analysis method analyses and locates the machine that generates the main waste, identifies the problem point in the machining line (eq. 2-5):

$$P\overline{Y}_i = \frac{1}{n_i}\sum_j^{n_i} Y_{ij}, i = 1, 2, \dots, t, \tag{2}$$

$$SSD_i = \sum_{J=1}^{n_i}\left(Y_{ij} - \overline{\overline{Y}}_i\right)^2,\ i = 1, 2, \dots, t, \tag{3}$$

$$\sum_{i=1}^{t}\sum_{j=1}^{n_i}\left(Y_{ij} - \overline{\overline{Y}}\right)^2 = \sum_{i=1}^{t} SSD_i + \sum_{i=1}^{t} n_i\left(\overline{Y}_i - \overline{\overline{Y}}\right)^2, \tag{4}$$

$$Y_{ij} - \overline{\overline{Y}} = \sum_{i'}\sum_{j'} c_{i'j'}Y_{i'j'}\ . \tag{5}$$

The technique of testing expectations according to student distribution to assess the quality stability of machines in process. The method of testing the expected deviation evaluates two processing machines (Machine A1 has assessed that the quality of the products after processing is unstable and Machine A2 is a new machine with the defective generation rate in the control area) is the product quality consistent? (eq. 6):

$$\left[(\overline{X}_1 - \overline{X}_2) < -Z_{\alpha/2}\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}, (\overline{X}_1 - \overline{X}_2) > Z_{\alpha/2}\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}\right]. \tag{6}$$

Statistical method measures the actual problem arising on the processing line, determines the specific location of the machine that gives rise to the problem point of product quality.

2.3 Analysis

Analysis of variance two factors evaluates the results of machining jigs running on machines, which affect product quality (specifically, jigs on machining center process surface dimensions) (eq. 7-11):

$$Y_{ij} = \mu_{ij} + E, \quad i = 1 \div a; j = 1 \div b, \tag{7}$$

$$\mu_{ij} = \mu + \tau_i + \beta_j, \tag{8}$$

$$SS_E = \sum_{i=1}^{a}\sum_{j=1}^{b}\left(y_{ij} - \bar{y}_i - \bar{y}_j + \bar{y}\right)^2, \tag{9}$$

$$\mathrm{MS_T} = \delta^2 + \frac{\mathrm{b}\sum_{\mathrm{i=1}}^{\mathrm{a}} \tau_{\mathrm{i}}^2}{\mathrm{a-1}}, \tag{10}$$

$$\mathrm{MS_B} = \delta^2 + \frac{\mathrm{a}\sum_{\mathrm{j=1}}^{\mathrm{b}} \beta_{\mathrm{j}}^2}{\mathrm{b-1}}, \tag{11}$$

with μ_{ij} – expectations turn out for experimental treatment *i*, block *j*, μ – expectations fade away, τ_i – expected deviation due to the effect of treatment *i*, *i=1-a*, β_j – expected deviation due to block *j*, *j=1-b*.

The multivariable experimental design technique for evaluating product jigs when processing and the technique for measuring the quality of product surface dimensions are the two main factors that give rise to surface scraps that do not meet customer requirements (eq. 12-15). Analysis of total sample variation:

$$\mathrm{SS} = \sum_{\mathrm{i=1}}^{\mathrm{a}} \sum_{\mathrm{j=1}}^{\mathrm{b}} \sum_{\mathrm{k=1}}^{\mathrm{n}} \left(\mathrm{Y_{ijk}} - \overline{\mathrm{Y}}\right)^2. \tag{12}$$

The sum of squares of the entire sample was analysed from the sum of squares of each part:

$$ss_E \mathrm{SS_E} = \sum_{\mathrm{i=1}}^{\mathrm{a}} \sum_{\mathrm{j=1}}^{\mathrm{b}} \sum_{\mathrm{k=1}}^{\mathrm{n}} \left(\mathrm{Y_{ijk}} - \overline{\mathrm{Y}}_{\mathrm{ij}}\right)^2, \tag{13}$$

$$\mathrm{MS_{AB}} = \mathrm{SS_{AB}}/[(\mathrm{a}-1)(\mathrm{b}-1)] \sim \mathrm{x}^2_{(\mathrm{a}-1)(\mathrm{b}-1)}. \tag{14}$$

Expectations of the mean squared of the observed samples:

$$\mathrm{MS_{AB}} = \sigma^2 + \frac{\mathrm{n}\sum_{\mathrm{i=1}}^{\mathrm{a}} \sum_{\mathrm{j=1}}^{\mathrm{b}} (\tau\beta)_{\mathrm{ij}}^2}{(\mathrm{a}-1)(\mathrm{b}-1)}. \tag{15}$$

Hypothesis testing the influencing factors that give rise to unsatisfactory product surface defects based on the distribution of the observed sample mean squares with τ_i, β_j – expected deviation, y_{ijk} – output variable value, e_{ijk} – experimental error, Y – output of experimental variance, μ – expectations of the output variable, i, j – indicator range.

Analysis of variance in univariate experimental technique evaluates the impact of jigs on the output quality of product surface quality (eq. 16-17). Model of output's variable, sum of squared variation of observed data:

$$\mathrm{SS_E} = \sum_{\mathrm{i=1}}^{\mathrm{a}} \sum_{\mathrm{j=1}}^{\mathrm{n}} \left(\mathrm{y_{ij}} - \overline{\mathrm{y}}_{\mathrm{i}}\right)^2. \tag{16}$$

Mean squared variation of observed data:

$$\mathrm{MS_T} = \sigma^2 + \frac{\mathrm{n}\sum_{\mathrm{i=1}}^{\mathrm{a}} \tau_{\mathrm{i}}^2}{\mathrm{a-1}}, \tag{17}$$

with μ, μ_i – expectations of output variable, E_i – experimental error, τ_i – expectation deviation.

Univariate analysis of variance, univariate and multivariate experimental design analysis, measurement of observed patterns and specific identification of the main causes of defective products arising on the machining line.

2.4 Improve

The Monte Carlo analysis technique simulates the improvement options and makes the decision to choose the most feasible improvement option out of the four options. Univariate variance test evaluates the response of jigs after improvement at a machining center machine (eq. 18). Hypothesis rejection domain H_0:

$$\left[S^2 < x^2_{1-\alpha/2,n-1}\sigma_0^2/(n-1),\ S^2 > x^2_{\alpha/2,n-1}\sigma_0^2/(n-1)\right]. \tag{18}$$

The fuzzy set-based decision-making technique evaluates the stability of the system after using improved jigs at the machining center. Fuzzy object techniques and statistical tests perform the selection of the most suitable machining center jigs improvement plan and evaluate the results apply improved jigs to practice with high marks and improve jigs stable operation over time.

2.5 Control

A machining center is an automatic processing machine, untrained operators are at risk of causing labour accidents. A computer vision system that recognizes human faces is proposed to be applied to control workers operating at each processing line. The computer vision system uses artificial intelligence techniques to identify the face of each processor corresponding to the machine position and extract images from the camera system. The machining center operator stands in the wrong position according to the factory layout, the computer vision system detects and the alarm sounds, the machining center operation system locks. The machining center program call system is supported by DNC technology. Operating principle of DNC system according to CIM principle. The barcode reader reads the order barcode at the machining center, the order code is transmitted to the production system and requires the DNC system to select the machining program at the machining center to respond. The combination of computer vision and DNC systems creates a perfect system for occupational safety and operation of automatic processing machines at the factory. A product quality measurement system is also proposed to be applied at each processing line, measuring equipment is connected to the measuring system and measurement data is automatically saved to the production system server.

3 RESULTS OF CASE STUDY AND DISCUSSION

3.1 Define

Analysing scrap data from March 2019 to March 2020 at the machining line, the surface error accounted for 0.33%. Frequency of occurrence of a number of defects on 30 products, Empirical CDF shows that the cumulative frequency of scrap rate in the process tends to increase.

The processing line (B1) has an error probability ratio p1 = 0.01 and B2 is p2 = 0.05, has an order of 20 products and does not know which processing line. Bayes formula gives the results P(B1/A) = 0.7613 and P(B2/A) = 0.2387, (eq. 1), proving that the B1 production line is 3 times more likely to generate unsatisfactory surface defects than B2.

The surface is not up to the standard and is unstable, causing time (35 minutes) to both checks and calibrate so that the product runs smoothly, at the assembly stage, and it takes time to re-check. The roughness of the product after processing, is a wasteful step. The value stream mapping chart of the current state of the processing line shows that the total lead time of a product is 1,190 minutes, the total cycle time is 995 minutes and the value-add time is 443 minutes.

3.2 Measure

Three machining centers (MC) are operating at line B1, Box plots show that MC 3 is the machine with the highest rate of waste generation (eq. 2-5), one-variable ANOVA analysis results in p-value = 0.001 and F-value = 68.86, standard deviation MC 1 is 0.596, standard deviation MC 2 is 1.184 and standard deviation MC 3 is 1.680, the pooled standard deviation is 1.23565, the F-value is quite large, and the p-value is close to 0, the conclusion is to reject the hypothesis H0, the rate of waste generation of the 3 machines is different. The standard deviation value of MC 3 is larger than the pooled standard deviation value indicating that MC 3 is a machining center that produces the scrap.

The mean plane dimension value of 50 machined samples at MC 3 is 34.45 mm (eq. 6) larger than the rejection area value of 33.95729 mm with 95% confidence interval, H0 is rejected, set size quality calculation of the machined surface dimension at MC 3 is unstable.

The mean deviation of the product flatness dimension between 50 samples machined by MC 2 and 50 samples machined by MC 3 is 0.96 mm (eq. 6), the rejection value of H0 with 95% confidence level is less than -0.67786 and greater than 0.67786, the mean deviation between the two samples falling into the rejection region and the rejected H0, the product surface flatness size between the two machines MC 2 and MC 3 is different.

3.3 Analysis

Experimental analysis of variance evaluates that machining jigs have an impact on the quality of product surface flatness, size, and surface flatness, for jigs to run sequentially on 4 MC machines at two processing lines, with a p-value of 0.041 less than 0.05 (eq. 7-11), H0 is rejected, machining jigs have an impact on product surface flatness dimension quality. The MS_B is 12.83 is much larger than the MS_E is 7.54, demonstrating that jigs have a strong influence on the surface flatness dimension quality.

Evaluation of machining jigs interaction conditions on surface flatness quality and surface flatness dimensioning methods have an impact on flatness dimension quality at the machining line (eq. 12-15). Considering the condition that jigs affect the flatness dimension quality, the p-value is $0.002 < 0.05$ and it is concluded that jigs influence the flatness dimension. Considering the method condition, the p-value is $0.0001 < 0.05$, concluding that the measurement method has an impact on the flatness dimension quality. Considering the interaction between jigs conditions and measurement method conditions, the p-value is $0.0186 < 0.05$, with a 95% confidence interval, the jigs and measurement method conditions have an impact on the quality of the flatness dimension and the measurement method. The above two conditions do not affect each other.

Repeat 5 times on the same machining jigs at 1 machine MC 3, p-value is $0.001 < 0.05$, null hypothesis H0 is rejected, F-value is $18.31 > 2.87$ (with 95% confidence interval). In conclusion, the difference between five times of jig experiment influences the plane size. The results of statistical analysis and experimental design show that machining jig is the main cause of unstable surface dimension quality, measurement method is also a factor to consider when implementing process improvement. The Failure Tree Analysis (FTA) model analyses the cause of surface dimensional instability errors, leading to measurement loss of calibration time, checking the smooth operation of the product after assembly. FTA analysis model for dimensional instability error of surface size. The results of the FTA analysis show that the type of product placement in the jigs is the main factor causing the instability of the surface dimensions.

3.4 Improve

Four improvement options are proposed, option 1 (A1) to periodically maintain jigs, option 2 (A2) to purchase new jigs, option 3 (A3) to improve jigs by adding steam sensors and creating a control system and option 4 (A4) combines the DNC system into the system of option 3. Present value (PV), present value probability P(PV), expectation and present value variance E(PV), V(PV). Calculate the above parameters for each option. According to the expected standard E(PV), which option has the highest expected value is considered the best solution, option A4 has the best value E(PV) = 65,000 USD, options A1, A2, A3 have the same expected value and equal to 60,000 USD. According to the

probability criterion P(PV < 0), the solution with the lowest probability is considered the best solution, option A3 is the best, with probability value = 0.0, followed by A2 and A4 = 0.1 and A3 = 0.2 is the final. According to the standard of variance V(PV), the option that gives the lowest variance value is considered the best option, the alternative A3 is the best and has the value = 2.5, followed by A2 = 3, ranked second. 3 is A4 = 3.85 and finally A1 = 5. According to the alternative selection criteria, option A3 (improve jigs by adding steam sensors and creating a control system) is considered the best of the four alternatives. Option A4 (combines the DNC system into the system of option 3) is the 2nd priority out of 4 options when making improvements and is followed by options A2, A1.

Option A3, drill a vent hole on the jig at the position where the jig is in contact with the product surface, the steam sensor is connected to the vent position, the signal filtering system is set up by MATLAB software with a low pass filter. Collect and process steam volume control signals. In case, the surface of the product is not adjusted to the jig, steam escapes, the signal processing system recognizes and sends out a red sensor signal, the processing system automatically locks, the machine cannot operate (Figure 1).

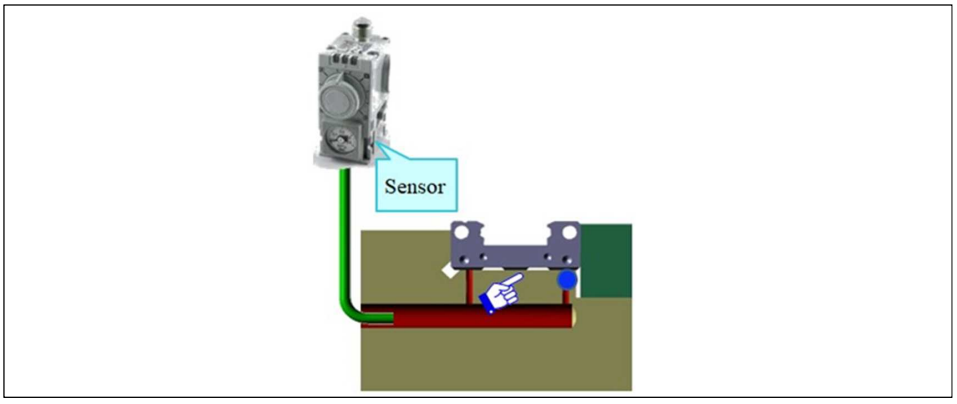

Figure 1 – Air Sensor System

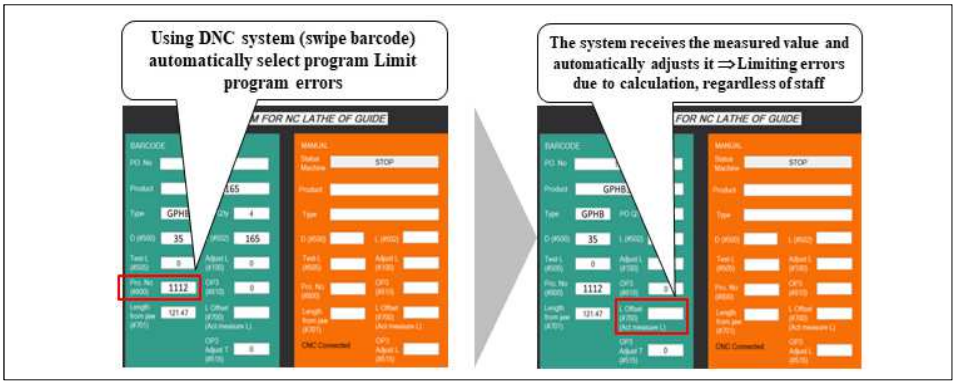

Figure 2 – DNC Program Screen Interface

Option A4 is further developed from the idea of plan A3, establishing a DNC system to automate the process, linking the machining center program to the management system. The barcode system acts as a bridge to call the machining program and update the machining tolerance system, update the product quality measurement results from the measurement system in real-time, the product dimension value is updated in the machining center program tolerance system table, and the DNC system automatically updates the offset table of the machining size tolerance parameter in the machining program according to the machined size of products in real-time (Figure 2). In case, the machining system and the measuring system have inconsistent results, the measuring system will automatically lock, and the machine system will be locked, the alarm will sound.

DNC signal processing and control system receives sensor signals and processes signals, measurement data from the measurement system is updated into the tolerance system, the system updates the machining program to update the dimensions. Quality of products from the system and control the machining program. In case the system does not match the value, the system is locked.

Deploy the DNC system to a machining center, run 30 samples consecutively and the dimensional variance values of 30 samples (eq. 16-17) is 1.44, with a 95% confidence interval of the null hypothesis being less than 0.83 and greater than 2.36. The 30-sample variance does not fall into the rejection region, H0 is accepted, the product quality is guaranteed, proving that the DNC system works stably, gives satisfactory results, and does not generate waste products.

Overall performance evaluation of the entire improved machining system (applying DNC system, automatic measurement system at each machining line and real-time data collection) including operational features (P: Process), operating cost (C: Cost), availability (A) and sensor signal processing system software program (S: Software), Rating scale includes good (E), good (S), average (A) and bad (I). A sample of hitting and establishing a fuzzy matrix is as follows (19).

$$R=\begin{vmatrix} & E & S & A & I \\ P & 0.1 & 0.3 & 0.4 & 0.2 \\ C & 0.0 & 0.1 & 0.8 & 0.1 \\ A & 0.1 & 0.6 & 0.2 & 0.1 \\ S & 0.1 & 0.4 & 0.3 & 0.2 \end{vmatrix} \quad (19)$$

Standard weight vector: W = [0.4 0.3 0.2 0.1], the integrated evaluation fuzzy set is: E = W x R = [0.1 0.3 0.4 0.2]. From the results of the fuzzy set, the performance of the system is assessed as average A. The DNC system and the signal processing measurement system operating for production meet the requirements but need further improvement.

3.5 Control

The post-improvement system has turned the machining line from semi-dynamic to fully automatic operation, requiring operators to be trained with sufficient operating skills, in case the operator is not skilled enough, it can cause problems, because the machine system is fully automatic, the proposed facial gender recognition computer vision system is put into use to control the layout of automatic machine operators. After being trained and qualified to operate automatic machines, employees' faces are taken at different levels and each employee takes 100 pictures, taking 70 training pictures for the system. The computer vision system and the remaining 30 images were used to test the computer vision system. The computer vision system recognizes human faces as an artificial intelligence (AI) system. Each employee is assigned a fixed working position according to the machine layout and trained skills, if the employee arbitrarily moves to another area, the computer vision system will recognize and issue a warning at the same time. The measurement system is locked.

4 CONCLUSION

The DNC system and sensor system are set up at the machining center (Figure 3) and operational in production, improving productivity, reducing waste, and reducing product production time.

Rebuild the future value stream map and as a result total lead time is reduced by 20 minutes compared to pre-improvement in future value stream mapping. Scrap products decreased by 59.66% per year, the production line assembly productivity increased by 7.8%. Calculating all related costs and monthly depreciation cost of 500 USD for jig improvement cost, the profit is 678 USD per month and 7,636 USD per year.

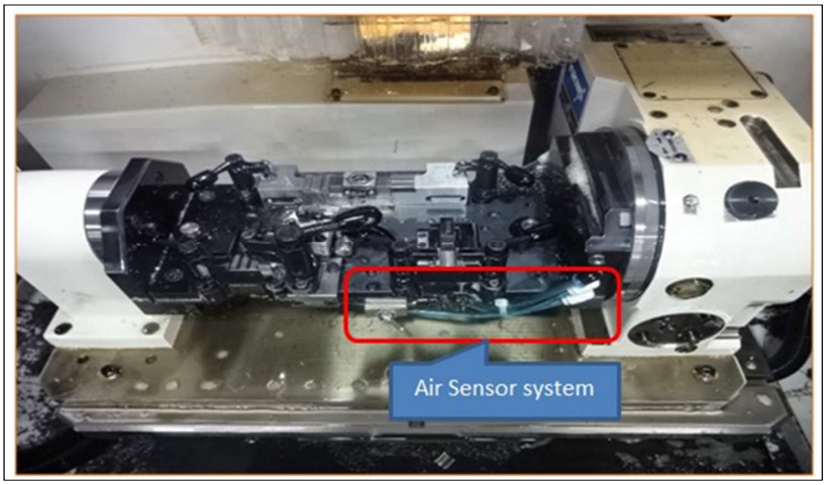

Figure 3 – Actual Improved jig of MC

The sensor signal processing system in the environment is gradually incomplete and still generates many noise signals, the measurement system has not yet developed a system to check external products by computer vision system, signal feedback system. Measuring and updating offset tolerance is not perfect. The above issues are research directions open to researchers.

ACKNOWLEDGEMENTS

Sincere thanks to the Department of Cybernetics and Biomedical Engineering, VSB–Technical University of Ostrava, 17. Listopadu 15, 708 33 Ostrava, Czechia and Van Lang University, Ho Chi Minh City, Vietnam to support this research.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

The Main Benefits of Application of Six Sigma for Productive Excellence

DOI: 10.12776/QIP.V26I3.1712

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Received: 2022-07-05 Accepted: 2022-11-22 Published: 2022-11-30

ABSTRACT

Purpose: The present paper addressed the application of the Six Sigma method for process management to reduce the variability and scrap of packages manufactured at a company located in the city of Rio de Janeiro.

Methodology/Approach: Exploratory research was conducted to understand the context, analyse, and create familiarity with the problems identified in the company, making them more explicit.

Findings: Through Define, Measure, Analyze, Improve, Control (DMAIC) the company was able to identify the main causes of customer complaints and the factors that led to these complaints. Using management tools, it was possible to solve the problems with packaging outside the specifications, which was the reason for complaints from customers. The benefits of this research were the identification and analysis of the quality management tools.

Research Limitation/Implication: The present research had as a limitation the application of the method is only one company, so it is proposed as a future study of the application in different production processes of different organizations.

Originality/Value of paper: It was evidenced that there is a positive relationship between the application of Quality management methods and company billing, as there was an increase of 1.7% in company billing. In past surveys, new possibilities for improvement to be addressed emerged, making the team aware of the need to continue the process of continuous improvement.

Category: Research paper

Keywords: six sigma; quality tools; quality management; total quality management

1 INTRODUCTION

The purpose of quality is to analyse and correct non-conformity situations existing in the production processes. The achievement of customer satisfaction creates work routines which include tools and standards that make it possible to evaluate if the defined parameters are being met, so that the finished products are within the tolerance standards, enabling full internal and external satisfaction (Bastas and Liyanage, 2018; Li et al., 2018; de Sales et al., 2022; Teixeira et al., 2021). Starting from the premise of what constitutes quality, companies must adopt a quality management policy that is efficient and effective in continuously improving processes, thus achieving better results, customer loyalty, and improved business strategy, taking into account environmental issues (Bravi, Murmura and Santos, 2019; Barbosa et al., 2020; Carvalho, Santos and Gonçalves, 2020; Silva et al., 2020; de Araujo et al., 2021). The demand for quality has given rise to a series of technical standards, such as ISO 9001, which is a tool to document the culture of organizations consisting of requirements for managing the production of products and services (Fonseca and Domingues, 2018; Chen and Li, 2019; Barbosa et al., 2021), where new skills are nedeed (Doiro et al., 2017; Sá et al., 2019; Santos et al., 2021). Therefore, to fulfill requirements in certain processes requires the adoption of working methods aimed at standardization and control, the Six Sigma model is one such example (Fonseca and Domingues, 2018; Bravi, Murmura and Santos, 2019; Costa et al., 2019). Six Sigma, a disciplined methodology, can be applied in an organized way through a problem-solving method called Define, Measure, Analyze, Improve, Control (DMAIC), using quality tools in the development phases of small to large projects and continuous improvement (Antony and Kumar, 2012; Sharma et al., 2018; Ishak et al., 2019; Sá et al., 2020; Rodrigues et al., 2019). However, the non-convergence between developed and developing countries remains (Yülek and Santos, 2022). According to the context of quality management, this article has the following research question: what is the relationship between the application of quality management methods and corporate revenues? To answer this question a case study was conducted in a packaging company located in the city of Duque de Caxias – RJ. The objective was to apply the Six Sigma method, using the DMAIC tool, to reduce the variability and scrap of packaging manufactured by the company.

This work is divided into six sections. Section 1 introduces the study, as well as presents the research question and the objective. Section 2 contains the theoretical framework. Section 3 describes the research method. Section 4 presents and discusses the results. Section 5 concludes the study. Finally, in Section 6, the references used in the research are mentioned.

2 THEORETICAL FRAMEWORK

Six Sigma is a strategic management tool, aimed at elevating the performance and productivity of companies. It is focused on client satisfaction. This satisfaction is obtained by working for continuous improvement of quality and processes. Six Sigma is disciplined to statistics. What marks in the method, is the structuring formed by the use of tools that allow statistical study and analysis of the variabilities inherent in the processes (Hakimi, Zahraee and Mohd Rohani, 2018; Pereira et al., 2019; Ponsiglione et al., 2021). DMAIC as a tool that, when used, enables the identification, quantification, and minimization of recurring problems in processes and improves their performance after implementation. When Implementing Six Sigma using the DMAIC model, one should present it logically, in a coherent sequence and defined by the phases DMAIC (Arafeh et al., 2018; Costa et al., 2019; Rifqi et al., 2021).

Considered a methodology that enables the application of Six Sigma, the DMAIC, seeks in five stages presented in an organized way, the development and implementation of projects (Alshamlan et al., 2022; Daniyan et al., 2022; de Sales et al., 2022). The stages are organized into phases according to Figure 1.

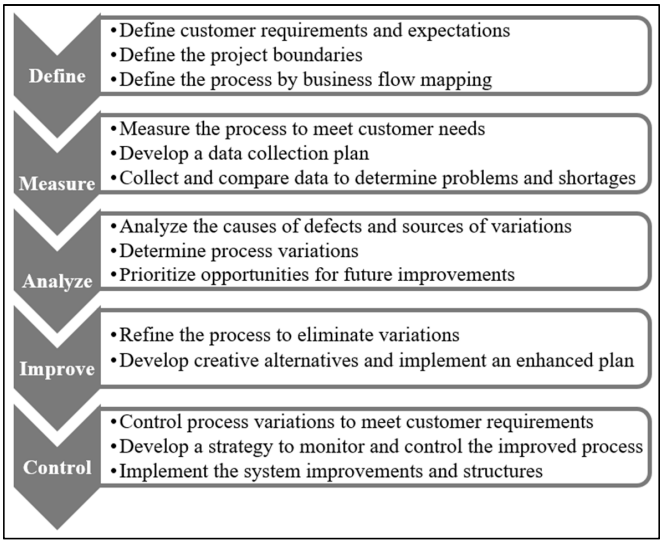

Figure 1 – DMAIC Flow (Improta et al.,2017; Shamsuzzaman et al., 2018)

The implementation of Six Sigma starts initially by focusing on the customer's needs. To obtain success with the adoption of the method, it is necessary to listen to the client and have consistent criteria for performance analysis. The organization must have financial resources, trained personnel for the development of the adopted methodology, and the involvement of other areas of the company in the process (Laureani and Antony, 2018; Muraliraj et al., 2018; Cardoso et al., 2022). The DMAIC uses in its steps some technical tools and methods used in quality management that can be used in an integrated way in

cycles of continuous improvement of process and products. These, aim at optimization in the planned stages (Muraliraj et al., 2018; Suharno and Zagloel, 2019; Dutta and Jaipuria, 2020). Quality tools consist of a methodological process to assist organizations in problem solving. They organize the understanding of techniques that lead to obtaining diagnosis, generating and analyzing decision alternatives (Hakimi, Zahraee and Mohd Rohani, 2018; Park, Dahlgaard-Park and Kim, 2020; da Silva et al., 2021). Examples of tools for quality management are (Table 1).

Table 1 – Quality Management (Improta et al.,2017; Shamsuzzaman et al., 2018)

Quality Tool	**Objective**
Check Sheet	A structured and prepared form of data collection and analysis that can be used for various purposes
Pareto Diagram	Applied to prioritize the problems as it shows in a bar chart which factors are most significant
Brainstorm	Maximum exposure of ideas focused on the solution of a problem
Ishikawa Diagram	Search for the causes of the problems
Attribute Control Chart	Control product characteristics that do not need a measuring instrument to be known
Software for Statistical Study	Optimization of data analysis that assists in the management of tasks inherent to Quality management
Production Autocontrol	Prevent a defect from passing to the next process phase

3 METHODOLOGY

In the present study the approach used was exploratory research with the purpose of understanding the context, analysing and creating familiarity with the identified problems in the company, making them more explicit (Yin, 2017; Kothari and Garg, 2019). The context of the case study is described in sections 3.1 and 3.2 where it is possible to identify initial benchmarks using quality tools and statistical data of the problems to be solved among the outlined framework. Known the real scenario of the process in the production line, it is established the goals of performance and quality to be achieved. The problems encountered in the initial situation were treated with solutions methods resulting in a new situation that was deployed and analysed with quality tools.

3.1 Problem Analysis

The problem addressed stems from complaints about the quality of a 1,000ml bottle designed for the packaging of motor oil. The company produces it using the blow molding process, where a heated plastic tube is inflated by air from a compressor. The transformation of the product takes place when a tube of the heated raw material is attached to a split mold and is then filled (blown) with the

desired shape. The raw material used in this process is a thermoplastic, presented in the shape of small grains. To produce its packaging, the company specifically uses High Density Polyethylene.

The parameters specified in the package design can vary due to the control conditions of temperature, pressure, speed, and time. For the new product, variations in specifications occurred in the manufacturing process (Zgodavova, Lengyel and Golemanov, 2008). These variations caused dimensional deviations, specifically in the neck diameter, a defect internally known as neck 'ovalization', and problems in neck height. These deviations were identified by the company's quality control and registered in an electronic spreadsheet. Though, the bottles with the above-mentioned deviations presented good functionality in the customer's filling line because the non-conformities did not interfere in the product performance and were conditionally released to the customer.

The acceptance of the product under these conditions was possible due to the possession of the Assegura Quality Certificate. The client granted this certification after the supplier went through an evaluation process, which attested that its products went through a qualification process and became suitable to be received, through test certification, waiving the receiving inspection. Quality is Assured is a partnership between supplier and customer that confers a level of confidence about products or services, which reach the expected quality, meeting the needs.

The company researched, having the Assured Warranty Certificate, and performed the control of nonconforming outputs. However, there were variations in its specifications and products were delivered with defects considered tolerable in the knowledge that the malfunctions did not interfere with the functional performance of the product. However, the dimensional deviations of the bottleneck were controlled defects known to the company and its customer. For a period, the customer accepted the deviations, aware of the history that proved that such conformities did not impact their process.

The client is a large company in the automotive lubricant industry, located in the city of Rio de Janeiro. It went through considerable internal changes, which consisted of changes in the workforce, certification in standards, changes in the policy for evaluating its suppliers, and winning over more discerning customers, who would submit it to periodic audits at their facilities. The changes impacted the results of the packaging manufacturing company, specifically, the receiving process by its customer, who opted to perform visual and dimensional inspections by sampling on the received packages and agreed to no longer accept products in a conditional state of quality. After this new procedure the complaints regarding bottle neck sizing increased significantly. They impacted the approval time for releasing the bottles to the customer's filling line, increased scrap due to internal Quality Control rejections, and reduced throughout 2018 the amount of packaging delivered to the customer. These facts resulted in a loss of 1.9% of annual revenue.

Given the performance in 2018, the company's board of directors requested improvement actions from those responsible for the unit. Soon, those responsible for the unit, knowing that the bottles presented good functionality in the filling line, proposed an improvement project that aimed to adjust the specifications of the technical design to the measures achieved by the manufacturing process. Their main arguments were the low cost of the project, the sustainability of the action, and the historical records of the daily dimensional analysis of Quality Control, which registered over a period, the divergences of the specifications established in the packaging project with the result of the manufacturing process.

3.2 Data Collection and Numerical Survey

The information to build this case study was acquired through a structured interview, which collected information about the actions taken by the packaging production company, located in the city of Duque de Caxias – RJ. The company used the DMAIC methodology and developed actions to improve its process in sequenced phases. Starting with the Define phase, followed by the Measure, Analyze, Improve, and Control phases, which presented the actions taken to solve the existing problems in the company's packaging production process. For the project, the team used the following quality tools: Check Sheets, the Pareto Chart, the Ishikawa Diagram, the 5W2H, Control Charts, and the statistical study by Minitab software. As a complement, the control phase presents the control methods adopted to guarantee the improvement stage actions, with actions aimed at identifying the existence of variations that may occur and affect the final product quality of the company's products.

4 RESULTS AND DISCUSSIONS

4.1 Define Phase

The Define phase used the Project Charter, a document that presents the activities of the team involved in the project, involving them in the project objectives (Costa, Silva and Pinto Ferreira, 2017). The objectives were: adjusting the specifications of the technical design of packaging to the achieved measures by the production process to reduce scrap; reducing rejections at the customer's receiving stage; Delivering a greater quantity of 1,000ml per day; Satisfying the customer, increasing the guarantee of use of the products delivered; and Increasing sales by 1.5% per year.

Table 2 – DMAIC Timeframe

Month		Jan. 2019	Feb. 2019	Mar. 2019	Apr. 2019	May 2019	June 2019
Phases	Define						
	Measure						
	Analyze						
	Implement						
	Control						

The project was carried out by employees involved in the bottle production process, people who had statistical data and information about the product design, employees from the Project, Quality, Production and Mechanical Maintenance sectors. The project was presented and executed according to the schedule shown in Table 2.

4.2 Measure Phase

The bottles were sized daily and had their data posted on a Check Sheet. The out-of-specification measurements presented in the check sheet reflected the reasons for complaints received by customers during 2018, which was the major cause of the reduction in revenue, but it was necessary to organize the data and visualize the relevance of the problem through a Quality tool. To do this, the team used the Pareto chart (Suharno and Zagloel, 2019).

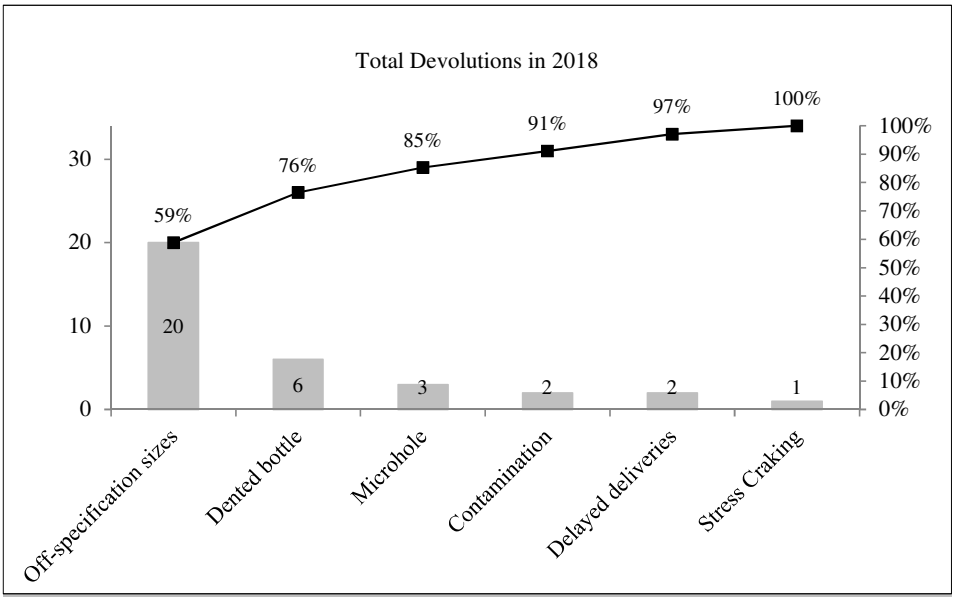

Figure 1 – Return Causes Flow

The complaints received from the customer were studied statistically, making it possible to identify that the complaint for not meeting the specifications represented 59% of the total. The percentage of each cause of return is shown in Figure 1 (Pareto Chart).

4.3 Analyse Phase

In this phase, after analysing the data and generating ideas for discussions, a Brainstorming session was done by a group of voluntary members to reach the solutions to the problems. The purpose of using the tool was the development of the team, the launching and the specification of the participants' opinions, focusing on solving the problem quickly and satisfying the customers (Krotov and Mathrani, 2017). As recommended, the chosen leader was the one who had the ability to synthesize the suggestions and take what was useful. The aim was not to waste time at this stage so that the length of the meeting could be set before its start.

Based on the results of the Pareto chart, the team used the Ishikawa diagram to search and analyse the roots of the problem. The team concluded that the problem was the "machine factor", because its equipment and accessories were not able to fully reproduce the defined specifications of the bottle. Figure 2 shows the result of the survey of the inherent to the customer's complaint factors.

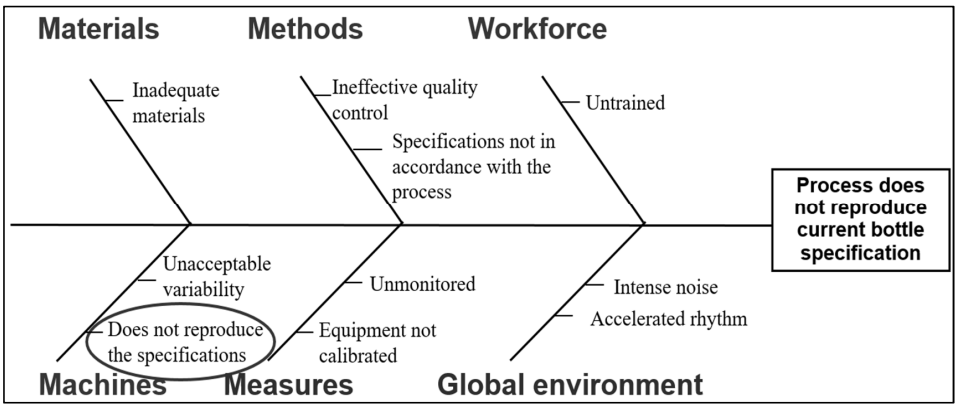

Figure 2 – The Result of the Survey of the Inherent to the Customer's Complaint Factors

After defining the factor responsible for the problem, the team came up with two alternatives to correct the specifications, which would be: adjusting the bottle specifications to the current process or making modifications in the mold and accessories to achieve the parameters and continue with the current specifications.

4.4 Implement Phase

In the implement phase, the solutions and ideas presented in the previous phase had to be planned and tested. Actions were planned for solving the problem. The first action was to correct the problem, because adjusting the specifications according to the outcome of the process, the problem would be solved (Costa, Silva and Pinto Ferreira, 2017; Dutta and Jaipuria, 2020).

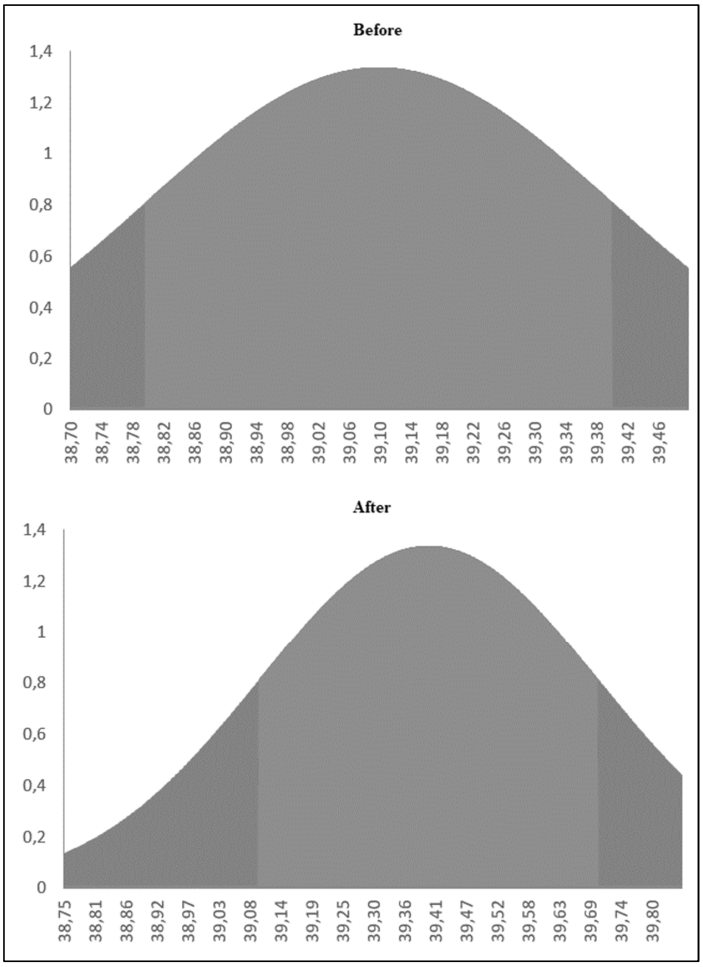

Figure 3 – Bottleneck Diameter Capability Study

The first action was performed according to the statistical study of the data recorded in the check sheet. The Minitab software commands read the stored information and generated data for the capability study of the stored information, the current specification values and the new specification suggestion. The term capability is related to a kind of control and measurement of the process capacity to repeat the parameters of a given specification. A controlled process may not have the ability to accurately replicate and meet desired limits (Costa, Silva and Pinto Ferreira, 2017; Pereira et al., 2019). The study performed of the data

showed the behaviour of the process in relation to the current specifications, from which it was possible to see the limits of the process. With this result, a new specification was developed for the diameter and height of the bottle neck. In Figure 3, the bottleneck diameter study performed by the Minitab software.

In the first graphic of Figure 3, the process specification presented samples were above the upper specified limit (LSE) and that they did not reach the target of the project specification. The second graph, already with the new limits, suggested that the specifications should be modified. An adjustment of the values in relation to the target was proposed, raising the lower specified limit (LEL) by 0.05mm and the upper specified limit (ULS) by 0.35mm.

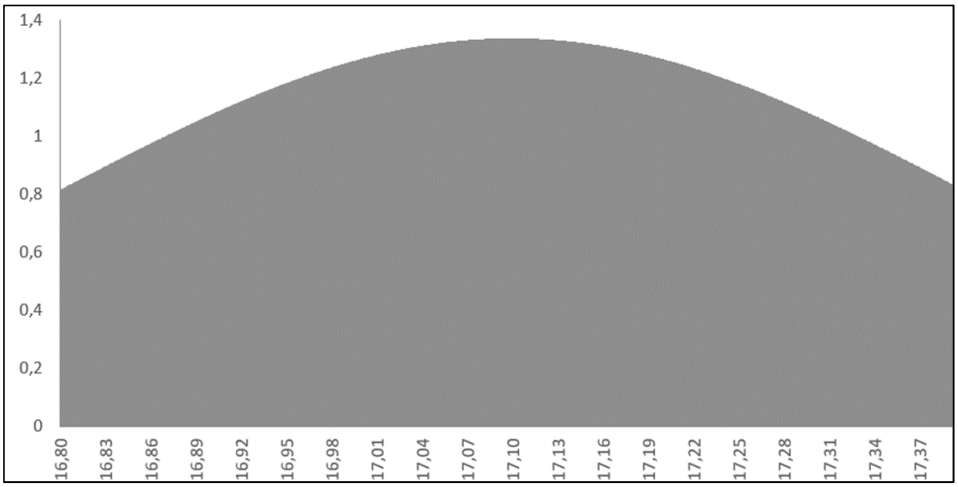

Figure 4 – Bottleneck Height Capability Study

In Figure 4, the process presented outside the specified lower and upper limit samples. Therefore, they did not reproduce the design specification. From the result, the second chart proposes the increase of the limits, so that both the process and the design specifications can be guaranteed.

4.5 Control Phase

This phase aims to ensure that the implemented improvements are kept over time. For this, quality control mechanisms must be established (Shamsuzzaman et al., 2018). To perform the production self-control, checkpoints were created within the production line, containing tables with computers to record the visual aspects of the packages, process parameters and records of the results of the "pass no pass" (poka-yoke) gauge tests, used to evaluate the neck ovalization. The SPC (Statistics Control Process) of the variables was performed using control charts by attribute.

The use of the self-control provided greater control over the manufactured product, from the identification of defects to the records that will help in future

studies of the process and expand the control over the product that was previously performed exclusively by the Quality Control sector. A standard procedure for self-control was developed and incorporated into the Quality System. The implementation took place after training was given to the employees about the methodology procedure, which approached the awareness of the importance of package quality evaluations and the search for quality according to the customer's voice. The methodology was applied not only to the 1,000ml bottle but to all other types of packaging produced at the plant.

In Figure 5, it is evident that the improvement actions had a satisfactory result. The out-of-specification measures, which previously represented 59% of the complaints, do not appear in the graph. There was a reduction in the other problems that were scored before. Dented bottles are now the main reason for complaints, representing 50% of the total complaints, however, defective units appear in fewer quantities in 2019.

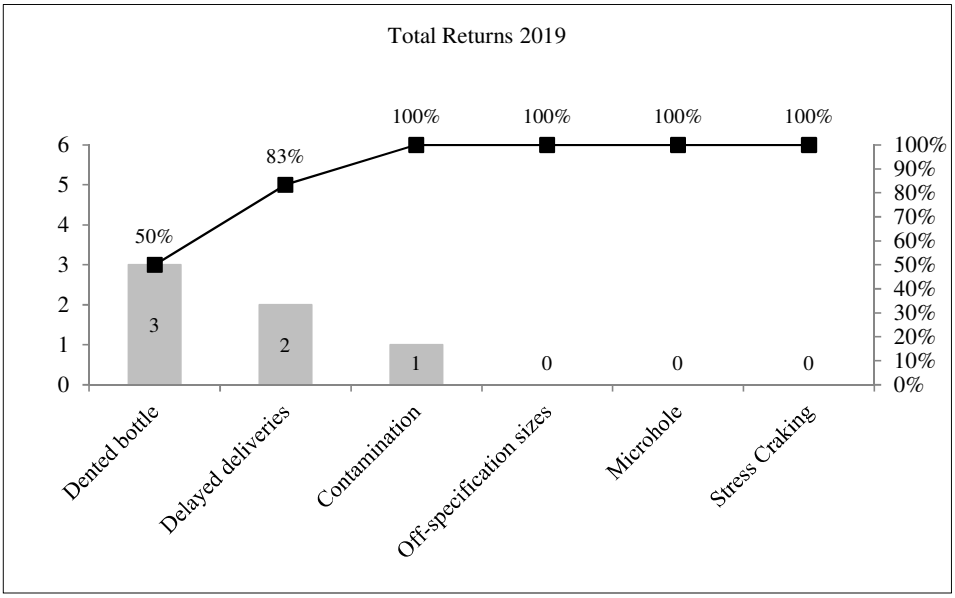

Figure 5 – Total Returns 2019

As the implementation of quality tools and quality management methods, the reduction of failures and improvement of effectiveness are evidenced in Figure 5. With the reduction of waste, increased efficiency and effectiveness of the manufacturing process, the reduction of expenses with defective products and the increase in the quantity of products produced are observed. Therefore, quality management helps increase revenue by reducing waste and defective products.

To adjust the bottle specifications to the optimized process or make modifications to the mold and fittings to the current specifications the customer needs to agree. Because the product must meet the demands of the end customer.

5 CONCLUSION

The practical benefits of this research were the identification and analysis of the quality management tools that could help to improve the bottle production process and the direct gains of the organization. The research managed to use the DMAIC to improve the production process and thus reducing waste and improving the final quality of the product and reducing customer complaints, thus reducing spending on rework. Through DMAIC, the company was able to identify the main causes of customer complaints and the factors that led to these complaints. Hence, the objectives of the study were achieved. It was evidenced that there is a positive relationship between the application of quality management methods and company billing, as there was an increase of 1.7% in company billing. Using quality management tools, it was possible to solve the problems with packaging outside the specifications, which was the main reason for complaints from customers. Among the main tools applied in the company studied, the DMAIC were highlighted.

In past surveys, new possibilities for improvement to be addressed emerged, making the team aware of the need to continue the process of continuous improvement. In this context, future studies should be conducted to identify the relationship between top management commitment to quality management and business sustainability. The present research had as a limitation the application of the method is only one company, so it is proposed also as future study of the application in different production processes of different organizations.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Emergence of Product and Service Innovations of Different Level of Novelty in Knowledge Intensive SMEs: The Role of Open Innovation Patterns

DOI: 10.12776/QIP.V26I3.1753

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Received: 2022-09-06 Accepted: 2022-11-22 Published: 2022-11-30

ABSTRACT

Purpose: The aim of the contribution is to evaluate the importance of domestic and foreign collaborative ties between knowledge-intensive SMEs and knowledge sources for the creation of product and service innovations which we differentiate according to the spatial level of novelty.

Methodology/Approach: In order to test the validity of the hypotheses which were justified in the context of previous research we adopt an econometric approach and specifically, due to the nature of the dependent variable, the logistic regression.

Findings: The results support the hypotheses that the determinants of innovation in SMEs vary in case of innovations with different level of novelty. Open innovation practices are crucial rather for SMEs delivering innovations of products and services novel on national and international markets.

Research Limitation/Implication: The research does not reflect the frequency of innovative products and services at the enterprise level as well as the impact of new products and services on turnover.

Originality/Value of paper: In particular, the study brings new insights into the determinants of product innovation of a lower degree of novelty applied in local and regional markets which can be an important source of development for low-density economies.

Category: Research paper

Keywords: innovation; open innovation; knowledge-intensive enterprises; small and medium size enterprises; internationalization

1 INTRODUCTION

In the competitive environment of the global, innovation-led economy of the 21st century, the original linear paradigm of innovation (Von Hippel, 1988) no longer finds significant support in practice. In order to remain competitive in rapidly changing markets, companies must have the capacity to take advantage of knowledge and technological opportunities from both the internal and external environment of the company (Cheng and Chen, 2013).

However, we still cannot consider research on factors affecting innovation emergence and open innovation (OI) patterns as sufficient (Lopes and de Carvalho, 2018), due to a multi-level, dynamic nature of innovation (Bogers et al., 2017). The pool of existing empirical research on the topic of drivers of innovation performance and OI practices within firms is mostly composed of studies focusing on innovation in large and medium size enterprises, high tech firms, manufacturing firms and firms of various isolated economy sectors (Ebersberger et al. 2021). We lack in scientific literature linking the investigation of prerequisites for innovation and justification of knowledge-intensive entrepreneurship concept. Thus, the study elaborates the role of knowledge flows under basic OI paradigm preconditions in case of those that are told to be "in most cases innovators" (Malerba and McKevley, 2018). We will investigate the utilization of in-house innovation approaches and knowledge generated in external environment leading to innovation in case of a knowledge-intensive small and medium sized enterprises (SMEs) (Eurostat, 2013). Therefore, we build a sample of enterprises falling under different industries, which can be considered as rare in innovation emergence research (Dziurski and Sopińska, 2020).

The discussion on role of collaboration networks in case of emergence of innovations that are novel on different spatial levels can be considered just as emerging (Goméz, Salazar and Vargas, 2020; Pasciaroni and Barbero, 2021). This study is to our best knowledge the first to adopt the approach of classifying innovation novelty in relation to spatial levels (new to international, national, regional and local markets), which is in line with approaches used in Community innovation surveys (Knell and Srholec, 2005). Also, due to the extensive pool of variables available for this empirical study, our efforts can be considered as a robustness check as we believe that when elaborating the determinants of innovation, it is desirable to check the robustness of results of other empirical studies by utilizing modified mix of regressors in case of different countries with different innovation ecosystem. Analysis is based on data collected within the Monitor of Innovation Activities in Knowledge Intensive Industries, a nation-wide survey implemented in conditions of the Slovak Republic. Secondly, the study is a respond to a request (Smallbone, Saridakis and Abubakar, 2022) to specifically focus on the evaluation of the impact of external knowledge, acquired within the international collaborative ties on the innovative performance of enterprises of different level of novelty.

We build on results of Hsieh et al. (2017) that propose to investigate the difference in impact of foreign and domestic knowledge on innovation performance of enterprises. Thus, this study will contribute to family of inbound studies.

2 THEORY BACKGROUND

Innovation in a private enterprise arises through a very complex multi-stage process (Dodgson, Gann and Salter, 2006), with multiple facets, while these processes are often requiring cut-edge technologies and diverse human capital and financial capital (Randhawa, Wilden and Hohberger, 2016). Given the complexity of the innovation process, empirical research in recent decades has often adopted the approach of modelling the entire innovation process. As some authors emphasize (e.g. Hsieh et al. 2017, or West and Bogers, 2014), this type of approach is important especially due to complexity of innovation processes and potential utilization of both internal and inbound knowledge (Hansen and Birkinshaw, 2007). Even the process of creation of OI lies on a certain scale between make – or – buy (Nieto and Santamaría, 2007). In the second half of the 20th century, it was even more natural for industry to maintain an innovation process based on their own "in-house" research. The entire innovation cycle was de-facto allocated in one space and the results from the own scientific research activity were kept secret as they tended to trespass the boundaries of the company in the form of spill-overs, or via formal commercialization (Al Ansari, 2013). However, research and development as a key and highly valued function of the company is increasingly becoming the subject of outsourcing, offshoring, or both (Weigelt, 2009). A number of authors (e.g. Cassiman and Vouglers, 2006; Grimpe and Kaiser, 2010) brought evidence that internal and external knowledge are jointly a prerequisite for innovation growth, or that the marginal return to internal R&D increases with the intensity of R&D outsourcing. However, with the rapid development of OI, the question arises whether the external acquisition of knowledge leads to an increase in the innovation performance in case of diverse types of innovations (Grimpe and Kaiser, 2010).

There are, for example, fundamental differences in the way large companies and SMEs innovate, which is reflected in the structure of OI activities in enterprises of various size-groups (Parida, Westerberg and Frishammar, 2012). In the scientific literature, the consensus still prevails that scientific research activity in a company grows with the size of the company (Lopes and de Carvalho, 2018). However, SMEs are considered the backbone of the EU economy mainly due to the fact that they are an essential source of job opportunities, create entrepreneurial spirit and are able to flexibly search for innovative opportunities (Ženka, Šťastná and Pavlík, 2021). Small and medium-sized enterprises have the advantage of lower levels of bureaucracy, flat hierarchies, quick access to information, and generally tend to be very efficient in adapting and specializing their products for the needs of specific markets (Lesáková et al., 2017).

In recent years, the concept of the so-called knowledge-intensive firms (Malerba and McKevley, 2018) have attracted a lot of attention, whereas these enterprises are defined as belonging to industries with increased requirements for knowledge due to their innovation dynamics. But the propensity towards OI action is not integrated within the definition of this construct. This is due to the fact that, for the needs of the EU, Eurostat (2013) defines knowledge-intensive enterprises as enterprises of industries that traditionally employ more than 30% of employees with university level of education based on NACE classification.

Applying the inbound innovation model brings several key benefits for companies. It allows them to share the costs of innovation activity (Katz, 1986), gain access to knowledge that is not available within the internal knowledge pool and overcome constraints of path dependency (Grimpe and Kaiser, 2010). By gaining access to external knowledge, companies increase the pool of internal knowledge, use synergies from the intersection of internal and external knowledge, or increase the effectiveness of their own research and development (Cohen and Levinthal, 1989; Laursen and Salter, 2006; Gómez, Salazar and Vargas, 2020). On the other hand, the acquisition of external knowledge also increases the company's costs, and require to overcome the number of barriers accompanying the application of external knowledge. Salge et al. (2013) distinguish three types of such costs: identification costs, assimilation costs and utilization costs. Haans, Pieters and He (2015) found inverted U-shape relationship in the additive combination of two increasing functions describing the benefits and costs of increasing the proportion of external R&D investments used as inputs in the innovation process (Gómez, Salazar and Vargas, 2020).

Particular attention was paid to the investigation of the determinants of product innovations, service innovations, process innovations, or organizational and marketing innovations in accordance with the frequently used OECD classification (2007). Within the OI literature, various patterns of inbound and outbound OI have been explored. Inbound OI can be defined as the use of external knowledge or technology internally, while outbound innovation refers to the transfer or dissemination of knowledge or technology to an external environment (Cassiman and Valentini, 2016). Inbound OI studies seek to explain how combining the internal R&D and external knowledge, utilizing fully externally created knowledge, or use of external know-how and creative capital can lead to OI (Laursen and Salter, 2006; Cassiman and Veugelers, 2006; Kim and Park, 2010; Lopes and de Carvalho, 2018) whereas outbound OI studies explain how enterprises raise competitiveness via export of intellectual property, know-how and knowledge (Parida, Westerberg and Frishammar, 2012; Hung and Chou, 2013).

Research of the emergence of innovations phenomenon has traditionally been linked to factors of company performance, such as business turnover, Return on Investments (ROI), or Return on Sales (ROS) (Cassiman and Veugelers, 2006; Popa, Soto-Acosta and Martinez-Conesa, 2017), market share (Cheng and Huizingh, 2014), ROS, or ROI. As a traditionally investigated determinants of

innovation we also consider in-house R&D indicators, such as share of R&D expenditures, R&D intensity, or employment in R&D (Berchicci, 2013). Some attention was put on the history and experience with the commercialization of knowledge in the form of intellectual property, measured e.g. by number of patents deposited, or cited (Chen, Chen and Vanhaverbeke, 2011). The relationship between the availability of high-quality, educated human capital (Diebolt and Hippe, 2018) and innovative performance was also measured, while human capital is a prerequisite for both the effectiveness of in-house R&D as well as the successful utilization of external knowledge. External knowledge search strategy in terms of breadth and depth of collaboration was examined first by Laursen and Salter (2006). Among contingent variables, many authors found support for Schumpeterian mark II hypothesis that probability of innovating products and services grows with firm size in terms of number of employees and level of turnover (e.g. Chang, 2003; Lichtenthaler, 2007; Berchicci, 2013). Many authors found the relationship between innovation performance and firm age (Berchicci, 2013; Chen, Chen and Vanhaverbeke, 2011). Within the models of innovation emergence other authors often controlled a type of industry (Chang, 2003; Cheng and Huizingh, 2014), country (Chang, 2003), or competitive intensity (Cheng and Huizingh, 2014).

Our intention is to evaluate the role of collaborative ties in the emergence of product and service innovations that have been applied on the "higher markets" (international and national markets) and the lower markets (regional and local markets) with an emphasis on examining the influence of BREADTH (Laursen and Salter, 2006) of collaboration, as well as the HEIGHT of collaboration (which we can understood as the highest spatial level of collaboration with partners). Such research is especially important because, for example, innovations of small producers and service providers, which often have the character of imitation (Hrivnák, Roháčiková and Schwarcz, 2020), can be also a source of rapid growth of rural economies (Porter et al., 2004). Therefore, the following research hypotheses are formulated:

H1: As the BREADTH of sources of knowledge exchange grows, the likelihood that knowledge-intensive SMEs will deliver new product and service innovations to local and regional markets increases.

H2: As the BREADTH of sources of knowledge exchange grows, the probability that knowledge-intensive SMEs will deliver product and service innovations new to national and international markets increases.

H3: As the HEIGHT of knowledge exchange grows, the likelihood that knowledge-intensive SMEs will deliver new product and service innovations new to local and regional markets increases.

H4: As the HEIGHT of knowledge exchange grows, the likelihood that knowledge-intensive SMEs will deliver new product and service innovations new to national and international markets increases.

H5: The EXISTENCE of knowledge flows between knowledge-intensive SMEs and public R&D institutions (universities, Slovak Academy of Sciences) increases the probability that these enterprises will deliver product and service innovations new to local and regional markets.

H6: The EXISTENCE of knowledge flows between knowledge-intensive SMEs and public R&D institutions (universities, Slovak Academy of Sciences) increases the probability that these enterprises will deliver product and service innovations new to national and international markets.

H7: The EXISTENCE of knowledge flows between knowledge-intensive SMEs and private R&D institutions increases the probability that these enterprises will deliver product and service innovations new to local and regional markets.

H8: The EXISTENCE of knowledge flows between knowledge-intensive SMEs and private R&D institutions increases the probability that these enterprises will deliver product and service innovations new to national and international markets.

H9: The EXISTENCE of knowledge flows between knowledge-intensive SMEs and public R&D institutions located in other countries increases the probability that these enterprises will deliver product and service innovations new to national and international markets.

The research framework beyond the composition of our model will be further explained in subsection 3.2.

3 METHODOLOGY

3.1 The Survey

The empirical analysis is based on survey "Monitor of Innovation Activities in Knowledge Intensive Industries" that was collected in conditions of the Slovak Republic in first months of 2022. Survey was devoted to target entire population of knowledge-intensive, small and medium sized enterprises active in the Slovak Republic, which number reached 3,485 enterprises in 2021 due to Register of institutional units in SR; however, only in case of 2,971 enterprises in population was possible to ensure the contacts necessary for an enquiry. From 2,971 responded enterprises, 261 expressed an interest to participate on the survey in the three conducted rounds of data collection. This means that the survey achieved a return rate of 8.79%, which can be considered as a success considering the fact that population is composed of private sector actors.

The initial list of companies for responding was created manually using the "Register of Institutional Units in the Slovak Republic" database. Enterprises in the register were filtered based on the criteria of enterprise size in terms of the number of employees, legal form and main economic activity according to the

NACE rev. 2 classification. We used the Eurostat methodology (2013) for the classification of knowledge-intensive industries, which was compiled for the needs of the EU based on the criterion of employing at least 30% of employees with completed III. degree of education (university education). This decision is related to the assumption that a higher dynamic of creation of product and service innovations can be identified in case of these industries (Malerba and McKevley, 2018).

The questionnaire contained 26 questions, of which six were open-ended and the other eight were semi-closed. The questionnaire evaluates individual aspects of innovation activity as "predominant tendencies". This survey did not aim to quantify the number of product and service innovations delivered by knowledge-intensive SMEs, given the fact that the aim of the survey was rather to collect more detailed descriptions of various innovations that enterprises brought within three-year period. For the purposes of our research, it is important that the questionnaire collected data on the collaborative ties of knowledge-intensive SMEs in gaining access to knowledge within networks with other types of spatial actors together with information on the spatial levels of these collaborations.

3.2 Research Framework and the Model

In this empirical study, we firstly want to identify enterprises which innovated products and services within the obtained sample in a defined period of time. We distinguish innovators according to the dominant degree of novelty of the identified innovative products and services. In the data, we have available information on whether the "described" innovations of products and services were mostly new at 4 spatial levels, namely: local, regional, national and international. This taxonomy can be understood analogously as a novelty at the level of local, regional, national and international markets.

However, we decided to integrate the local and regional spatial level as a "lower spatial level", especially considering the size of the NUTS III regions in the Slovak Republic in terms of population and area and markets, which are "small" compared to Western European countries. Thus, we will simultaneously integrate the national and international level as "higher" and thus we will use the dual classification of the novelty of innovations at a lower and higher spatial level. In terms of our model, two binary dependent variables will classify whether the given enterprise (1) introduced product and service innovations in the examined three-year period, or (0) did not innovated. These variables are further referred to as *isln* (innovation new on lower spatial level) and *ishn* (innovation new at higher spatial level).

As for independent variables, we need to control a relatively high number of variables that have already been identified as determinants of innovation in the literature. Considering the distinction between innovations of lower and higher spatial novelty, we will; however, bring valuable information about the differentiation of their impact in the case of these "types" of product and service

innovations. Therefore, we incorporated independent variables within the model I. (eq. 1): *size municipality* (the size of the municipality in which the company is located), *ownership* (express whether the venture is in foreign, or domestic ownership), *prod_serv* (distinction between knowledge intensive manufacturing and knowledge-intensive services), *employees* (refers to total number of employees), *share tertiary* (share of employees with tertiary education), *exp R&D* (average share of budget devoted to R&D), *exp technology* (average share of budget devoted to getting access to technologies), *state public funds* (express whether the venture got access to external funds for innovation action crossing 50,000 euro).

The observed independent variables are the subject of further differentiation of the models, as in the case of model II (eq. 2) we monitor the influence of 5 variables on the ability to bring new product and service innovations at a lower and higher spatial level in accordance with the established hypotheses: *breadth coop* (the number of sources of knowledge in terms of other spatial actors), *height coop* (the highest spatial level of collaboration with knowledge source), *kflow public R&D* (the existence of knowledge flows from universities, or Slovak Academy of Sciences), *kflow private R&D* (the existence of knowledge flows from private research centres), *kflow cluster* (the existence of knowledge flows from other enterprises within cluster). The model III (eq. 3) monitors the impact of two other observed variables, which are a response to the requirement of a direct investigation of relationship between internationalization of the company's knowledge links and innovation performance. These are factors *kflow foreign firms* (the existence of knowledge flows from other foreign firms) and *kflow foreign R&D* (the existence of knowledge flows from foreign universities and public R&D centres). The ability to bring innovation was investigated in the time period between 2018-2020, while the data for variables *exp R&D*, *exp technology*, *state public funds* and all types of knowledge flows were purposely time-lagged (2017-2019) to avoid the bias resulting from not respecting the natural succession of activities in the innovation process. From what has been said and due to binary nature of our dependent variables, we formulate 3 multiple logistic regression models, whereas, in the case of all of them, we distinguish the influence of these determinants on the emergence of new innovations on the regional and local market (*isln*) and on the national and international market (*ishn*). The composition of these theoretical models is as follows:

$$isln\ and\ ishn = \beta 0 + \beta 1 * size\ municipality + \beta 2 * ownership + \beta 3 * prodserv + \beta 4 * employees + \beta 5 * share\ tertiary + \beta 6 * exp\ R\&D + \beta 7 * exp\ technology + \beta 8 * state\ public\ funds \quad (1)$$

$$isln\ and\ ishn = \beta 0 + \beta 1 * size\ municipality + \beta 2 * ownership + \beta 3 * prodserv + \beta 4 * employees + \beta 5 * share\ tertiary + \beta 6 * exp\ R\&D + \beta 7 * exp\ technology + \beta 8 * state\ public\ funds + \beta 9 * breadth\ coop + \beta 10 * height\ coop + \beta 11 * kflow\ public\ R\&D + \beta 12 * kflow\ private\_R\&D + \beta 13 * kflow\ cluster \quad (2)$$

$$isln\ and\ ishn = \beta 0 + \beta 1 * size\ municipality + \beta 2 * ownership + \beta 3 * prodserv + \beta 4 * employess + \beta 5 * share\ tertiary + \beta 6 * exp\_R\&D + \beta 7 * exp\ technology + \beta 8 * state\ public\ funds + \beta 9 * kflow\ foreign\ firms + \beta 10 * kflow\ foreign\ R\&D \quad (3)$$

4 RESULTS

4.1 Sample and Descriptive Results

Our sample consisted of 261 respondents who were managers of an equal number of enterprises from knowledge-intensive manufacturing industries and knowledge-intensive services, which can be classified based on the employment criterion (10-250 employees) among small and medium-sized enterprises.

The sample can be considered as fairly balanced, i.e. approximately copying the distributions in the population from several perspectives (especially the size of the municipality where the company headquarters is located, the size of the company, the legal form, or the type of ownership – domestic or foreign). There is an increased share of manufacturing companies in the sample (compared to the share of 10.85% in the population) and at the same time, the distribution of companies in the sample does not fully correlate with the population in terms of affiliation to groups of NACE industries. This problem; however, cannot be avoided due to the widespread responding of the entire population (3,485 knowledge-intensive SMEs).

The first descriptive results already indicate that the factors such as location of the company headquarters, the length of venture existence, the number of employees, the form of ownership, or the nature of output (producers and service providers) probably do not play a significant role in clarifying which companies in the economy predominantly deliver innovations of products and services. In total, up to 43.29% of the companies in the sample declare that between 2018-2021 they delivered new product and service innovations (with the criterion of at least the initial phase of the market application of these products and services at the time of the survey). Some information is provided by the decomposition of innovators into those who in 2018-2020 brought innovations applicable mainly on the local and regional or national and international markets. Here we already observed an indication of a pattern that innovations of a lower degree of novelty arise to a greater extent in the conditions of smaller, rural settlements while the innovations of products and services of a higher degree of novelty arise more frequently in regional centers and capital city.

Similarly, a higher frequency of enterprises introducing new products and services for local and regional markets can be observed among young and small enterprises. There was observed a slight increase in the share of innovators among larger companies. Post-socialistic transitional economies suffer from the problem of slow compensation for a significant decline in research and

development activity after 1989 which explains the increased share of innovators among larger foreign-owned enterprises. Even despite the fact that a significant part of foreign large or medium-sized companies allocated in the countries of the former socialist bloc do not allocate research and development units within these countries. In the sample, we identified a balanced share of innovators in the groups of knowledge-intensive producers and knowledge-intensive service providers, but in the service sector we find an increased share of innovations applicable mainly in local and regional markets.

Table 1 – Distribution of the Sample and Share of Innovators within NACE Groups of Industries

NACE groups of industries	Share on total	Did not innovated	Novel on local and regional markets	Novel on national and international markets
Administrative and support services	8.02%	71.43%	23.81%	4.76%
Real estate activities	3.82%	80.00%	0.00%	20.00%
Transport and storage	3.05%	100.00%	0.00%	0.00%
Financial and insurance activities	4.20%	72.73%	9.09%	18.18%
Information and communication, ICT	9.16%	25.00%	20.83%	54.17%
Professional scientific and technical activities	9.92%	57.69%	11.54%	30.77%
Other activities	8.02%	76.19%	9.52%	14.29%
Agriculture, forestry and fishing	5.34%	57.14%	28.57%	14.29%
Industrial production	20.23%	35.85%	16.98%	47.17%
Construction industry	8.40%	59.91%	31.00%	9.09%
Accommodation and catering services	1.91%	60.00%	20.00%	20.00%
Arts, entertainment and recreation	5.73%	33.33%	40.00%	26.67%
Wholesale and retail trade, repair of motor vehicles and motorcycles	2.29%	83.33%	0.00%	16.67%
Education	3.05%	37.50%	0.00%	62.50%
Healthcare and social assistance	6.87%	50.00%	38.89%	11.11%

In terms of sector affiliation of innovators in the sample (Table 1), the largest share of innovators (exceeding 50% of respondents from the sector) was identified in the sectors of information and communication technologies, industry, arts, entertainment and recreation, education and health care. In case of some sectors, an increased share of innovators generating predominantly new products and services for the local, or regional market (especially healthcare and social assistance, arts, entertainment and recreation, construction industry, or agriculture, forestry and fishing) was observed. An increased share of innovators

capable of bringing new product and service innovations to national and international markets was identified in the education, information and communication technology, or industry sectors.

In the next step of the descriptive analysis, the novelty and the origin of innovation in the case of knowledge-intensive SMEs in the sample are discussed. Figure 1 displays prevailing models how innovations have been created in the sample. We can conclude that the importance of research and development carried out in-house should not be underestimated, as can often be observed in the OI literature. This is especially true in the case of industrial production enterprises. Up to 50% of industrial producers in the obtained sample delivered original innovations applied on the national, or international markets between 2018-2020. These innovations were created exclusively by in-house research and development. As for other sectors, prevailing patterns of OI can be observed in our sample. In the case of small enterprises producing innovations applicable to local and regional markets, it may be true that they increasingly seek opportunities to create new own products and services through imitation of established innovations in the external environment (especially in the case of enterprises with a similar product in larger cities). Most often; however, knowledge-intensive SMEs, which have brought innovations applicable mainly on the local and regional market, use the approach of adapting an existing product or service. It means that they bring their specific adaptation or improvement for application in the conditions of their own company.

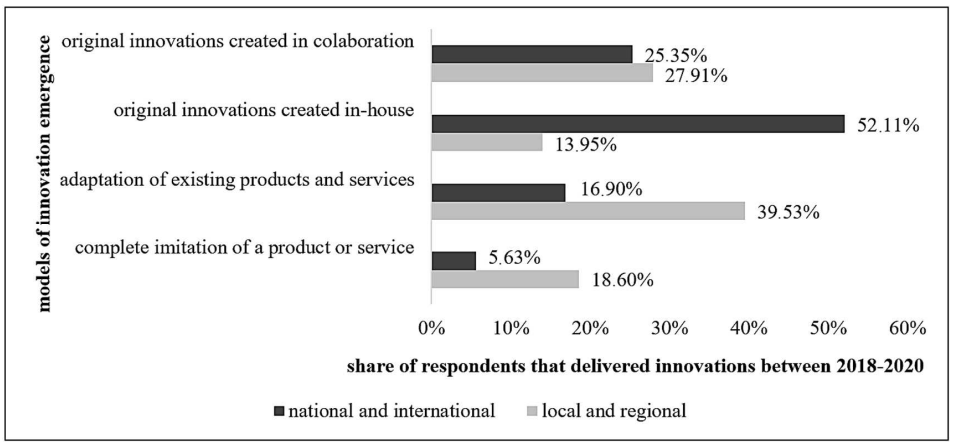

Figure 1 – Prevailing Models of Innovations Emergence in the Sample in Case of Innovations New on Local, or Regional and National, or International Markets

The survey also identified innovators who generate product and service innovations mainly in cooperation between two or more institutions on the development of original products and services. In the sample, we identified approximately 25% share of innovators that delivered new products and services through collaborative development.

As part of our descriptive analysis, we will work with the terms BREADTH and HEIGHT of collaboration on knowledge exchange. The survey collected data on highest levels of collaboration for the purpose of knowledge exchange in the case of innovators who mostly delivered innovations new to the local and regional markets or to the national and intern-national markets. Based on the results, it is possible to hypothesize that OI strategies and cooperation in the exchange of knowledge at higher spatial levels lead to the emergence of innovations with a higher degree of novelty, or applicability in wider markets. Producers of innovations novel at higher spatial level create collaborative networks in slightly higher extent with universities and Slovak Academy of Sciences, private research institutions, other enterprises both in own and different sectors and even with non-governmental organisations (NGOs). On the other hand, producers of innovations novel at lower spatial levels tend to collaborate in increased extent with NGOs and counselling services.

It is possible to state that the producers of new innovations on local and regional markets mostly cooperate up to the national spatial level and it is more difficult for them to gain access to international knowledge sources. In case of the ability to generate links of knowledge exchange with institutions that are a direct producer of knowledge (public and private R&D institutions), they cooperate mainly at the local and regional level. In general, in the sample, we found the highest spatial "height" of collaborations in case of other companies within the sector, as well as outside the sector. The knowledge-intensive SMEs generating new innovations at the national and international level are able to gain access to knowledge abroad from R&D institutions to a significantly greater extent, but they also cooperate with foreign governments. This fact is influenced by the structure of these enterprises in the sample, which are predominantly larger in terms of the number of employees, manufacturers and to a large extent were created with the foreign capital.

4.2 Results of the Model

For testing the hypotheses, we will use multiple logistic regression. The results of the model are presented in Table 2.

The results of the model demonstrate that it is not enough to differentiate innovations in terms of their type but also the degree of novelty or applicability in the conditions of various markets. We found strong evidence that the innovative activity of knowledge intensive SMEs grows with the size of the city of the company localization, both in the case of SMEs delivering mostly the innovations with a higher and a lower degree of novelty. At the same time, we found that foreign ownership of a company in the conditions of a transitional economy increases the probability of new product and service innovations on national and international markets. This is mainly due to the fact that medium-sized enterprises are mainly foreign-owned in the sample. We have also confirmed that even in the conditions of a post-socialist economy, the propensity

towards innovating products and services does not differ in case of knowledge-intensive manufacturing and knowledge-intensive services. Schumpeter's Mark II hypothesis favours innovation dynamics in large enterprises; however, within the range of SMEs groups based on employment criterion, we could not find strong evidence that product and service innovations occur to a greater extent in case of medium-sized than small enterprises.

The logical assumption is that high-quality human capital is key both for the company's own innovative activities, as well as the ability to utilize knowledge acquired from the outside. We found a strong dependence of innovators that deliver products and services new to local and regional markets on human capital with university degree of education. These results highlight even more already well-understood need to preserve educated human capital also in the rural regions.

Fully in line with the results of other studies, we have confirmed the impact of growth in R&D expenditures on the delivery of product and service innovations in the case of knowledge-intensive SMEs. This impact has been demonstrated only in case of enterprises that delivered innovations new to national and international markets.

On the contrary, expenditures on new technologies, which we understand both as production technologies and technologies necessary for the provision of services, proved to be important both for enterprises bringing new innovations at a lower and higher spatial level. Access to external sources of funding (state and public funds) of innovative activities only increases the probability of new product and service innovations new for national and international markets. This is due to the inability of small businesses to gain access to innovation grants, but also to the set-up of national schemes or the Research and Innovation Operational Program under the conditions of the Slovak Republic. The mentioned operational program often requires the company's own scientific and research activity and capacities to participate on calls, or a high degree of novelty of the resulting technologies in order to obtain public funding.

Further on, we will interpret the impact of the OI patterns indicators on the creation of new product and service innovations at a lower and higher spatial level. We found some statistically significant positive relationship between the number of types of horizontal partners with which there is a knowledge exchange relationship and the ability to bring product and service innovations. However, this is true only in case of innovators in sample that delivered product and service innovations new to national and international markets. Thus, we reject hypothesis H1 and accept hypothesis H2. However, the chances of bringing product and service innovations are more significantly increased by the highest spatial level at which the company has established external knowledge transfer links. Again, we identified this result only in the case of companies that delivered mainly innovations new to national and international markets. We therefore accept hypothesis H4 and reject hypothesis H3.

Table 2 – The Results of Multiple Logistic Regression

	Model I		Model II		Model III	
	isln*	ishn*	isln	ishn	isln	ishn
size municipality	0.7871* (0.0872)	1.4979** (0.2007)	0.7016** (0.0897)	1.6382** (0.2542)	0.7626* (0.0876)	1.4822** (0.2052)
ownership	0.8425 (0.4357)	3.8534** (1.7689)	0.5636 (0.3185)	5.3132** (2.9582)	0.6734 (0.3816)	2.4564 (1.2135)
prod_serv	2.2732 (1.0862)	2.2744 (1.1778)	1.5201 (0.7794)	1.8228 (1.0315)	1.978 (0.983)	1.721 (0.9271)
employees	0.9992 (0.0041)	1.0067* (0.0032)	0.9985 (0.0049)	0.9975 (0.0044)	0.9988 (0.0042)	1.0043 (0.0034)
share tertiary	16.2659*** (12.9414)	5.1598 (4.5986)	9.326* (8.362)	1.3665 (1.4138)	13.0377** (10.5458)	2.7897 (2.5809)
exp R&D	0.0062 (0.0202)	3542.50*** (10693.562)	0.0003 (0.001)	2682.19*** (7851.42)	0.0062 (0.0207)	2317.67*** (6823. 82)
exp technology	118.4316*** (159.3725)	31.8517* (49.6863)	104.0028** (150.1865)	4.5997 (8.3777)	102.3744** (137.8399)	26.9052* (44.868)
state public funds	1.3183 (0.5279)	4.8466*** (2.0283)	1.0854 (0.5155)	2.1742 (1.0501)	1.2869 (0.5311)	4.0456** (1.7592)
breadth coop			1.1096 (0.2131)	1.5767* (0.336)		
height coop			1.4208 (0.4345)	2.7158* (1.4011)		
kflow public R&D			0.989 (0.5475)	1.8479** (1.1065)		
kflow private R&D			4.5358 (2.4328)	0.4672 (0.2636)		
kflow cluster			0.3588 (0.2515)	3.7939* (2.477)		
kflow foreign firms					1.8226 (0.8573)	1.8552 (0.8916)
kflow foreign R&D					0.9646 (0.5208)	3.2096** (1.5079)
CONS	0.0901*** (0.056)	0.0014*** (0.0015)	0.0375** (0.0392)	0.0001 (0.0002)	0.1035 (0.0651)	0.0016 (0.0017)
number of obs	261	261	261	261	261	261
link test_hat	1.0248**	0.9525***	0.7556***	1.1648***	0.9067**	1.0046***
link test_hatsq	0.0104	-0.0387	-0.121	0.073	-0.0393	0.0031
lroc	0.7985	0.9193	0.8507	0.9418	0.804	0.9254
meanVIF	1.32	1.32	1.87	1.85	1.43	1.43

Notes: Statistical significance on levels * p < 0.05, ** p < 0.01, *** p < 0.001; standard errors in brackets.

We also wanted to test these relationships within the framework of a separate model by setting up dummy variables that express whether the enterprises in the 3-year period obtained external knowledge from public or private R&D institutions. We accept the hypothesis H6, and reject the hypotheses H5, H7 and H8. We found a relationship between gaining access to knowledge from public R&D institutions and the ability to bring product and service innovations, but again only in the case of innovators who brought innovations of a higher degree of novelty. A special case of acquiring external knowledge for innovation activity is drawing knowledge within the cluster. We also demonstrated a positive relationship between the company's participation in the cluster and the ability to bring product and service innovations in case of innovations with a higher degree of novelty. Finally, we accept hypothesis H9, as we proved relevance of "height" of access to knowledge in case of innovators bringing highly novel innovations. Internationalization of knowledge exchange is therefore the important assumption of innovation action, but this is not true in case of innovators bringing new adapted, or imitated products new on local and regional markets.

5 DISCUSSION AND CONCLUSION

This study supports the hypotheses that the determinants of innovation in SMEs vary in case of innovations with different level of novelty. Chang (2003) found that product and service innovations are also determined by the business and institutional environment in which venture is rooted. We have also identified that the propensity towards the innovation action grows with the size of the municipality of enterprise localization. Innovations of higher degrees of novelty arise in the conditions of transition economies within foreign companies located rather in larger municipalities. R&D expenditures, which significantly determine the appearance of product and service innovations as well in other studies (e.g. Chang, 2003; Cheng and Huizingh, 2014; Berchicci, 2013), do not play a significant role in the case of the emergence of innovations of a lower degree of novelty. It means that also in case of knowledge intensive manufacturing enterprises delivering mostly the innovations novel on the local level, own R&D capacity do not play significant role in the innovation process.

From a sales perspective, it was found that extramural R&D investments increased the proportion of sales from high novelty products more than from low novelty products (Goméz, Salazar and Vargas, 2020). Pasciaroni and Barbero (2021) found that with growing amount of collaboration networks, level of novelty innovation grows. We adopted slightly different approach to rather answer the question whether extramural knowledge support emergence of both innovation of higher and lower level of novelty. We found that collaborative networks are a prerequisite for the emergence of higher-novelty innovations that are new at a higher spatial level. Bjerke and Johansson (2015) found that inter-regional external interactions and knowledge exchange play a very central role in innovation processes in small firms where internal resources are very limited.

However, this may not apply in the conditions of small transitional economies. Among the innovators in the sample who introduced innovations of a lower degree of novelty, up to 86% were small businesses that just rarely collaborate with external knowledge sources. Impact of international knowledge inflows on capability to deliver product and service innovation (Smallbone, Saridakis and Abubakar, 2022) was also identified only in case of firms that delivered innovations novel to national and international markets. These entrprises cooperated in foreign environment mainly with universities and other public institutions. On the other hand, we found more crucial importance of educated and creative human capital (Diebolt and Hippe, 2018) and access to technologies (Cassiman and Veugelers, 2006; Hung and Chou, 2013) on emergence of lower-novelty innovations which can rather point on key role of internal resources for delivering the innovation of products and services in small firms. With growing size of a firm, propensity towards innovation of products and services grows (Chang, 2003; Lichtenthaler, 2007; Berchicci, 2013).

However, our findings regarding the importance of external ties and own human capital for innovation activity in small firms are far from sufficient for understanding patterns of lower-novelty innovation (Martínez-Román and Romero, 2013; Goméz, Salazar and Vargas, 2020). The assessment of innovative patterns of enterprises in rural areas can be considered as a particularly absent branch of literature. Considering the fact that up to 43.67% of respondents in the sample were located in rural areas, it can be assumed that small rural enterprises innovate mainly by adaptation, improvement, or imitation, and their innovation strategies and processes should be devoted to a much larger discussion in literature of innovation economy.

To conclude, it appears that inbound innovation practices lead to higher novelty innovations of products and services. Innovations new to local and regional markets will arise to a certain extent independently of access to external knowledge and the innovation ecosystem in the regional and national space. A significant part of the innovations brought by small businesses located in smaller settlements have the character of imitation or adaptation. Imitation and adaptation do not require a strong own R&D base but rather ideas, access to technology and high-quality and creative human capital.

Our research has also limitations that must be addressed for the appropriate interpretation of our results and conclusions. The research framework ignores the frequency of innovative products and services at the enterprise level, as well as the impact of new products and services on turnover. Considering the nature of the available data, we evaluated companies only as those that innovated products and services in the given time horizon and those that did not. At the same time, we worked with a relatively smaller sample of knowledge-intensive SMEs, which; however, results from the size of population in the conditions of a country the size of the Slovak Republic.

Considering the work with the data at the national level, our conclusions are applicable only in the conditions of one country, with potential similarities in the conditions of the V4 block, or in the conditions of the transitional economies of the post-socialist block.

Our conclusions encourage the opening of largely unexplored branches of research on innovation activity of SMEs. First of all, much more attention should be paid to the research of innovations with a lower degree of novelty, which are perhaps even more important for the competitiveness of small rural companies (Gómez, Salazar and Vargas, 2020). The fact that OI patterns mainly affect more novel innovations opens up the space for the missing discussion about the meaning and determinants of innovation in companies that only improve, adapt, or imitate individual types of products and services. Today, we are still not able to clearly explain the requirements of the adaptation process. At the same time, it is necessary to specifically focus on the investigation of the innovation process in enterprises located in low-density economies and OI patterns observable in case of enterprises rooted in a sparse local or regional institutional networks.

ACKNOWLEDGEMENTS

This work was supported by the Slovak Research and Development Agency under the Contract No. APVV-21-0099 “Efektívny manažment inovačne orientovaných územných klastrov”.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Product Innovation Paradigm of Modern Entrepreneurship

DOI: 10.12776/QIP.V26I3.1752

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Received: 2022-09-04 Accepted: 2022-11-19 Published: 2022-11-30

ABSTRACT

Purpose: The work is devoted to quantifying the main dependencies and contradictions between the introduction of innovation and corporate development of modern entrepreneurship forms.

Methodology/Approach: In this study, the main analysis method is the use of fuzzy knowledge bases to select the best management practices. The research allows one to understand the impact of innovation on the effectiveness of business models and what ways in management can be used to increase resilience to the influence of external factors.

Findings: The creation of new combinations of practices based on the knowledge base makes successful management of an enterprise's innovative development. To form a base, the results of global surveys and ratings of enterprises-leaders of innovative development became the basis.

Research Limitation/Implication: The study examines some aspects in the innovation management of enterprises in Canada. Canada's own specificity of innovative activity management caused the interest of research. Namely, an innovative society is being formed there based on a high level of education and knowledge, allowing higher rates of the country's development.

Originality/Value of paper: The paper examines the current economic and financial condition of innovative enterprises in Canada and the need to change the financial and economic policy to form a strong competitive position, in times of crisis and further economic growth. The results of this study can be applied in modern entrepreneurship, regardless of the scale of business.

Category: Research paper

Keywords: business incubators; business accelerators; small and medium-sized businesses

1 INTRODUCTION

Innovative development is the basis of competitiveness of modern economies and provides an opportunity for accelerated growth at the macro- and micro-level based on the creation and strengthening of intellectual potential in a global business environment (Zhao and Zeng, 2011).

The scientific groundwork of the early XXI century on innovative development management of an enterprise is based on:

- the concept of innovation ecosystem;
- open innovations;
- enhancing innovative development in the context of economic globalization;
- the use of the latest mechanisms of technology transfer;
- priorities of value-oriented management of enterprises;
- implementation of innovative business models;
- optimization of business processes of enterprises aimed at ensuring the productivity of innovation;
- implementation of successful management practices of the leaders of global innovation development (Seidler-de Alwis and Hartmann, 2008; Gernego, Dyba and Petrenko, 2019).

Today, the total scientific potential, covering innovation development management of enterprises, as well as methodological tools for the research processes of entities' innovation development, is large (Bousmah, 2021; Zarzewska-Bielawska, 2012; Maiti et al., 2020; Stepanova, Sibiryatkina and Sukhova, 2015; Gromova, Timokhin and Popova, 2020). However, the debate continues in academic circles, caused by the dynamics of innovative development and the need for its permanent scientific rethinking. In particular, the development of digital transformation and Industry 4.0, including big data, cloud computing, artificial intelligence, Internet of Things, robotics, etc., is most significant in today's environment. This led to new phenomena (in particular, digital innovation platforms, innovative business models) and new opportunities for managing enterprises' innovative development based on big data (data mining, business intelligence, machine learning, artificial neural networks) in conditions of fuzzy and incomplete data (Lüdeke-Freund, 2020; Ferreira, Fernandes and Ratten, 2017; Kuratko, 2017; Zhu, Liu and Xu, 2009).

The relevance of the research is determined by the fundamental place of innovation processes in business, often reflected in the complex and turbulent dynamics of modern economies. The study examines some aspects in the innovation management of enterprises in Canada. Canada's own specificity of innovative activity management caused the interest of research. Namely, an

innovative society is being formed there based on a high level of education and knowledge, allowing higher rates of the country's development.

Canada is making a fundamental change in its education, science, and technology, with the goal of embracing all societal structures and creating a new capacity for innovation. In fact, this is about changing values in Canadian society and the creation of a knowledge-based economy (Knubley, 2021; Kalu and Okafor, 2020). Thus, the study purpose is to quantify the main dependencies and contradictions between the introduction of innovation and corporate development of modern entrepreneurship forms.

Achieving this goal led to the following tasks:

1. systematize the methodological foundations of innovation as a theoretical category,
2. analyse the relationship between innovation and corporate development of various entrepreneurship forms,
3. study the dynamics and structure of investment in innovation at the level of a country and individual enterprises,
4. determine the specifics of innovation management in Canada, its trends and contradictions of development.

2 METHODOLOGY

The methodological basis of the work is a set of principles and methods. The systematization of dynamic abilities necessary for successful innovative development of enterprises was carried out. Global ratings were also investigated. A case study gave the opportunity to study management practices of enterprises-leaders of innovative development for their further generalization. For this purpose, a sample of enterprises was made, which was formed from the Canadian enterprises for 2016 and 2020, which produced innovative products (according to the statistical data).

Further, fuzzy logic and multiple fuzzy knowledge bases were used to select the best management practices and create their new combinations needed to successfully manage the innovative development of an enterprise in conditions of incomplete information. In further identifying the underlying trends and patterns in the development of innovative leaders, big data analysis was used (data mining, business intelligence, machine learning, artificial neural networks).

Innovative development management of enterprises based on dynamic capabilities can be represented as coordinated managerial actions on resource, process, and value aspirations. Innovation resource management includes a planning system and a sub-system of information support, which in today's environment is based on information technology (IT), big data, and analytical support.

To ensure comparability and homogeneity of indicators, the data on Canadian companies were studied in the context of separate groups formed on the basis of industry affiliation and the main direction of enterprises' activity. This allowed taking into account the industry peculiarities of their income and expenses formation and the influence of their innovative activity on the results of entrepreneurial activity.

The array of input data for Canadian enterprises was formed in the form of generalized indicators for the main industries. The impossibility of testing the proposed approach on specific enterprises in Canada is due to the lack of official statistical information about the indicators of their innovation activities.

The study of intra-industry trend of innovative development of enterprises in Canada was carried out in three stages. On the first – means of descriptive statistics in the context of each enterprise implementing innovative products were used. The analysis of the industries revealed (by interviewing stakeholders and processing statistical data) a significant differentiation in the trends of their development. At the second stage, to identify trends in the innovative development of enterprises, data mining methods were used as a tool to analyse the accumulated big data, especially relevant for decision-making in conditions of uncertainty. These methods are based on the classical principles of exploratory data analysis and model building. At the third stage, using the case study method, management practices of enterprises' innovative development were investigated.

The next step in the study of the relationship between innovation and business performance is to prioritize the identified factors and identify the main ones by ranking the impact of implemented innovation on changes in relevant indicators.

It is known that enterprises' innovative development is risky, poorly structured, and insufficiently formalized process but relevant to modern challenges. The essential feature of such development is its cyclicality associated with periodic changes in the basic innovation.

The paper proposes the use of approaches to the definition of linguistic terms and the formation of fuzzy knowledge sets to solve problems of this type.

The system of fuzzy logical equations is based on the knowledge matrix or isomorphic system of logical statements; it makes it possible to calculate output membership functions with fixed management system inputs:

1. Rules (*N*): linking inputs and output using vectors of type $V_k = \langle x_1, x_2, \dots, x_n, y \rangle, k = \overline{1,N}$, distributed according to the principle:

$$N = k1 + \dots + kj + \dots + km, \tag{1}$$

where *m* – the total number of values of the output variable; *kj* – the number of rules in the knowledge base corresponding to the output

variable *y*, identical to the value of *dj* (in the general case, $k1 \neq ... \neq kj \neq ... \neq km$).

2. Forming fuzzy knowledge sets (finding linguistic evaluations of variables and membership functions necessary for their formalization).
3. Applying the rules: U (The universal set of problem domain), a fuzzy subset of which F, $F \subset U$, is defined by the membership function $\mu^F(u)$, where $u \in U$ – set element$U$.
4. Fuzzy knowledge base:

$$\bigcup_{p=1}^{k_j}\left[\bigcap_{i=1}^{n}\left(x_i = a_i^{jp}\right)\right] \rightarrow y = d_j, j = \overline{1,m} \tag{2}$$

The scale of the knowledge base and algorithms for permanent selection and search for new combinations will avoid the trap of 'following the leader', because a new combination of independent leadership practices is, in fact, a managerial innovation, which creates the potential for new leadership (Gernego, Dyba and Petrenko, 2019). Based on the data from the enterprises, this method will be applied.

It is the proposed design that achieves the purpose of the study, as it allows one to assess the influence of variables and evaluate the degree of innovation in different enterprises.

3 RESULTS

Innovative enterprises are active, independent market entities that perform specific actions to directly search for new or diversify existing industries, thereby actively attracting financial capital and intellectual potential in this process.

The conditions under which enterprises achieve innovation leadership are characterized by instability, uncertainty, and stochasticity. In general, the problem of selecting the best management practice can be defined as follows: according to the external conditions to find such states and managerial impacts, which would provide a certain criterion with a better (minimum, maximum) value. Methods based on the theory of fuzzy logic are suitable for solving the problems of selecting the best management practices and creating new combinations of them necessary for the successful management of enterprises' innovative development. They allow one to effectively investigate situations that cannot be solved with the apparatus of binary logic.

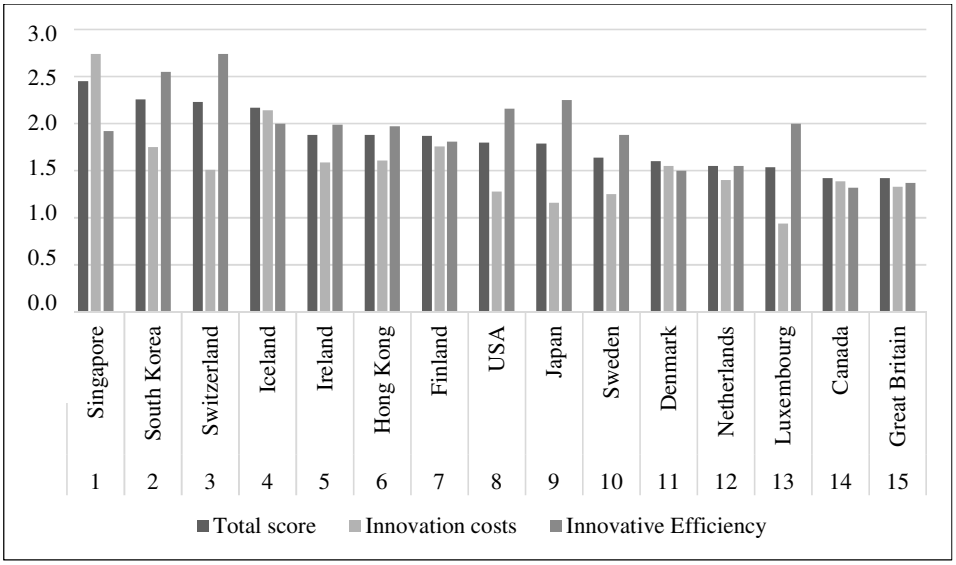
Such methods include, in particular, neural network, fuzzy, genetic algorithms, corresponding to a wide class of problems of enterprise innovation development

management. The basis of the theory of fuzzy logic contains definitions of the linguistic variable, the values of which are words or expressions of natural or artificial language, represented in the form of terms, methods of formation of fuzzy sets and inference rules.

Based on the way of organizing innovation process in an enterprise, one can distinguish three innovative enterprise models:

1. Innovation enterprise on the basis of internal organization. Innovation is generated within a firm by its specialized divisions based on planning and monitoring their interaction with the innovation project. To a greater extent it is characteristic of corporate type enterprises, which create internal venture.
2. Innovation enterprise based on external organizations with the help of contracts. The order for the creation and development of innovations is made between third-party organizations.
3. Innovation enterprise based on the external organization with the help of venture capital, when a firm to implement an innovative project organizes subsidiary venture capital firms, which attract additional funds.

One of the main objectives of a state in order to increase innovation activities among enterprises is the development of innovative entrepreneurship and infrastructure.



Notes: Index compiled by the World Intellectual Property Organization, Cornell University, and Insead International Business School. A total of 143 countries are represented in the ranking.

Figure 1 – Global Innovation Index 2020, Points

For innovative entrepreneurship it is important to have an entrepreneurial environment, which makes it possible to find appropriate organizational forms

for the implementation of ideas and innovations. Entrepreneurial environment is an environment that contributes to a search, preparation, and implementation of innovations. The elements of such an environment are: investors with free financial resources, commodity producers with free capacities that can be used to manufacture competitive products, and appropriate infrastructure.

At the same time, the practical implementation of legislative provisions encounters significant obstacles and does not always correspond to the approaches and principles established in international practice. The most common mechanisms of state support for innovation are presented in Table 1.

Table 1 – Modern Mechanisms of Financial State Support for Innovation

Country	**State support for innovation**	
	Organizational structures of institutional support	Forms of incentives
USA	Small Business Administration, National Science Foundation, Federal agencies, National Innovation System, American Association for the Advancement of Science, National Research Council, National Institute of Standards and Technology, National Technical Information Service, Office of Science and Technology Policy	Preferential taxation; investment tax credit; preferential treatment of depreciation charges; subsidies; earmarks from the budget; deduction of R&D expenses related to core production and trading activities from the amount of taxable income
Japan	State funds to encourage R&D activities, Small and Medium Venture Fund, Small Business Finance Corporation, Enterprise Development Assistance Center.	Soft loans, preferential taxation, subsidies
France	A special government organization, the French Society for the Promotion of Venture Capital, the National Center for Scientific Research, and the National Agency for Research Implementation (Anwar).	Subsidies, long-term loans, tax credits, credit guarantees, preferential taxation
	The National Agency for Advanced Research, a public-private bank to finance small innovative businesses, a science and technology fund, etc.	
Germany	Consortia of small innovative businesses, state specialized banks – Bank for Recovery Loans and German Equalization Bank, Ministry of Economy, Ministry of Research and Technology, Federation of Industrial Research Associations, Patent Center	Targeted non-repayable subsidies, grants, payment of technical expertise costs, soft loans, credit insurance system, tax discounts and rebates, accelerated depreciation, targeted bank loans
Canada	Canadian Ministry of Innovation, Science and Economic Development, Business Development Bank of Canada, Canadian Federation of Independent Business, the Canada Foundation for Innovation, Canadian Venture Capital Association	Concessional loans, subsidies, technical assistance, tax credit, preferential taxation
United Kingdom	Council for Science and Technology, UK Research and Innovation, etc.	Preferential taxation, subsidies, deduction of R&D expenses (cost of products (services)), credit guarantees

Considering the above, it is quite reasonable to attract targeted investment resources from the banking sector for innovation. At the same time, it is necessary to accentuate that today the share of banking sector in financing of innovations in Canada is not high. One of the basic external sources of receiving investment is medium – and long-term credits of banks. In recent years, the situation has been worsened by the instability of economic and political conditions, the high risk of providing funds for a long-term period, the scarcity and high cost of credit in the banking system.

The crisis that came with the onset of the pandemic has slowed down the development of the venture capital market. This is a global trend. According to statistics, the volume of investments in high-tech companies in the global market in Q2 2020 was $50.2 billion, which is 13% less than the same figure a year earlier (OECD iLibrary, 2005; Wipo, 2022). Overall, the number of deals fell by 9%. Now the idea alone is not enough to interest investors. In 2020, they are already looking at product readiness to enter the market. In this situation, large cities that want to become innovation centres will have to focus on improving the entrepreneurial ecosystem.

To ensure comparability and homogeneity of indicators, the data on Canadian companies were studied in the context of separate groups formed on the basis of industry affiliation and the main direction of enterprises' activity. This allowed taking into account the industry peculiarities of their income and expenses formation and the influence of their innovative activity on the results of entrepreneurial activity. One may note that, in addition to industry specifics, the results of enterprises' innovative activity can be influenced by national and regional characteristics of their operating environment. The array of input data for Canadian enterprises was formed as generalized indicators for the main industries. The impossibility of testing the proposed approach on Canadian enterprises is due to the lack of official statistical information about the indicators of their innovation activities. Cross-industry analysis, using data from the [BLINDED], initially implies additional model error in the calculations associated with not taking into account the factor of industry affiliation of enterprises, which must be considered when analysing the results.

The study of intra-industry trends in the innovative development of Canadian enterprises was carried out in three stages. On the first – means of descriptive statistics in the context of each innovative enterprise were considered. The analysis of industries revealed (by interviewing stakeholders of innovative enterprises and processing statistical data) a significant differentiation in the trends of their development (Table 2).

Table 2 – Descriptive Analysis of Innovative Enterprises (Calculated by the Authors Based on Galindo-Rueda, 2019; Canadian Business, 2022)

Industry	Period	Number of enterprises		Revenue, bln.		Revenue, mln			
		Analysed	Missed	Amount	Maximum	Mode	Standard error of the mean	Median	Standard deviation
Mechanical Engineering	2020	12,309	0	328.29	12.02	26.67	1.68	1.77	186.84
	2016	8,867	3,442	140.12	9.74	15.80	1.47	0.92	138.05
Manufacture of fabricated metal products, except machinery and equipment	2020	3,319	0	63.30	2.44	19.07	1.63	2.03	94.11
	2016	2,281	1,038	20.79	1.11	9.12	0.91	0.92	43.38
Production of computers, electronic and optical products	2020	672	0	19.61	1.93	29.18	4.80	2.91	124.33
	2016	523	149	7.99	1.35	15.27	3.31	1.63	75.62
Manufacture of electrical equipment	2020	977	0	45.15	5.85	46.21	7.92	3.21	247.58
	2016	684	293	19.68	1.87	28.77	4.77	1.82	124.72
Software Development	2020	2,023	0	75.89	5.67	37.51	4.39	3.99	197.61
	2016	1,446	577	38.13	2.82	26.37	3.93	2.31	149.32
Clothing and Footwear Manufacturing	2020	275	0	28.31	2.57	102.95	18.82	5.75	312.13
	2016	211	64	11.90	1.75	56.38	13.40	4.65	194.64
Businesses in the service sector	2020	337	0	48.31	12.02	143.34	41.91	3.74	769.38
	2016	234	103	23.10	9.74	98.70	43.73	4.26	668.89
Development of information and communication technologies	2020	4,468	0	44.38	2.20	9.93	0.90	0.94	60.18
	2016	3,328	1,140	17.03	1.15	5.12	0.58	0.48	33.69

In the second stage, to identify enterprises' innovative development trends, data mining methods were used as a tool to analyse the accumulated big data, especially relevant for decision-making under conditions of uncertainty. These methods are based on the classical principles of exploratory data analysis and model building. Therefore, their use opens up great prospects for managing enterprises' innovative development, determining the growth factors, performance evaluation, and forecasting innovative development.

The authors put forward the assumption that the rate of revenue growth combined with its volume may indicate the implementation of innovation. There is an assumption that significant differences in innovation development management can lead to constant growth or the formation of a 'broken' trend.

The results of applying data mining to identify innovative leaders among innovative enterprises by development trends and scale of activity allowed identifying six groups of them.

At the third stage, the management practices of enterprises' innovative development were investigated using the case study method (Table 3). Enterprises were selected so that each of the 6 types showed one most effective enterprise (with a level of profitability above 19%). It was proved that the scale of activity and pace of development significantly differ among enterprises applying different practices of innovation development. The empirical data were systematized in the context of different innovation types, as well as innovation protection by intellectual property means for enterprises of incremental and radical innovation types.

Table 3 – Qualitative Results of Canadian Enterprises' Innovation Activity, Obtained Using the Case Study Method

Type*	**Enterprise**	**I1**		**I2**		**I3**		**I4**	
		FI	II	FI	II	FI	II	FI	II
RB	A	m	m	h	h	l	l	l	m
IB	A1	m	m	h	h	l	l	l	m
RM	A2	h	h	m	m	m	h	l	m
IM	A3	m	m	l	l	m	m	m	m
RS	A4	h	h	l	m	m	m	m	m
IS	A5	l	m	m	h	m	m	m	m

Notes: According to the table results, the first letter – radical or incremental development, the other – the scale of businesses; I1 – product innovations; I2 – process (technological) innovations; I3 – marketing innovations; I4 – organizational innovations. FI – frequency of innovations; II – intensity of innovations; h – high; m – medium; l – low.

The mechanism of innovation impact on enterprises' financial results is mediated by the market, where competitive advantages are formed. The basis for the analysis of innovation as a source of enterprises' competitive advantage is the concept of dynamic capabilities, which developed on the basis of the resource approach. Dynamic capabilities, as organizational procedures for innovative development created by management, allow enterprises to create new ways (combinations) of using resources based on knowledge. They ensure the introduction of innovations and become a source of sustainable competitive advantage due to the inability of competitors to imitate them. One can note that large enterprises can introduce innovations by cooperating with startups or absorbing them. Applying the concept of dynamic capabilities relies on the human factor and is associated with the process of organizational learning.

Based on the analysis and combination of the resource theory and the theory of innovation, the key factors were identified. They influence the formation of competitive advantages of Canadian enterprises based on innovation in the knowledge economy. Such factors are:

- the intellectual component of human capital;
- state of corporate entrepreneurship;
- entrepreneurial behavioural characteristics (proactivity, innovativeness, and risk appetite) of management;
- ability to synthesize and apply current and acquired knowledge in pursuit of a business opportunity;
- ability to create, expand, and modify resources;
- ability to generate new knowledge based on a combination of experience and external sources, including communications with stakeholders.

Intellectual property rights protection has a significant impact on the strategy to protect innovation based on patents, copyrights, or trade secrets. In jurisdictions with a strong rights protection regime, an enterprise employs strategies of pure knowledge ownership; ownership of complementary or critical assets; and a strategy of focusing on R&D. An alternative to protecting an innovation by registering intellectual property rights is to protect it informally, which involves keeping the innovation secret. Intellectual property legislation is designed to strike a balance between incentives for creating innovations and using the results of inventions that have already been created. It is worth noting that the intellectual property protection procedure is lengthy within the life of a startup, and in many cases the process of active innovation can be more effective.

Innovation can affect various aspects of an enterprise, in particular its competitiveness, market share, the efficiency of fixed and working capital, labour productivity, and others. In accordance with this, the OECD recommendations 'Guidelines for collecting and interpreting innovation data' (Mazzucato and Tancioni, 2008) consider all factors reflecting the motives and results of innovation in 4 groups:

1. competitiveness, target market share, demand;
2. production and sales policy;
3. personnel and communication policy;
4. compliance with regulatory requirements and other factors.

Each of these groups includes a set of indicators, the change of which reflects a positive effect of enterprises' innovations in Canada. Groups of factors and innovation types are based on the data (Galindo-Rueda, 2019; OECD iLibrary, 2005) and are given in Table 4.

Table 4 – Factors Reflecting Motives and Results of Canadian Companies' Innovation

Group of factors	**Factors (indicators) of innovation implementation**	**The innovation type that is influenced by a certain factor**			
		Product	Technological	Organizational	Marketing
Competitiveness, target market share, demand	Repositioning of products for which demand is declining	+			
	Expanding the range of goods and services	+			
	Developing environmentally friendly products	+			
	Increasing or retaining market share	+			+
	Entering new markets	+			+
	Improving product presentation and awareness				+
	Reducing the time to respond to customer inquiries		+	+	
Production and sales policy	Improving the quality of goods and services	+	+	+	
	Increased flexibility in the supply of goods and services		+	+	
	Increased ability to produce and deliver goods and services		+	+	
	Reduced labour costs		+	+	
	Reduced raw materials costs	+	+	+	
	Reduced costs for the design of new products		+	+	
	Reduced production downtime, optimized time for pre-production preparation		+	+	
	Compliance with technical industry standards	+	+	+	
	Reduction of operating costs in the provision of services		+	+	
	Increasing the efficiency and speed of raw material deliveries and shipment of finished products		+	+	
	Setting up information support		+	+	

Group of factors	Factors (indicators) of innovation implementation	The innovation type that is influenced by a certain factor			
		Product	Technological	Organizational	Marketing
Human Resources and Communications Policy	Establishing communications and interaction between business units			+	
	Activation of technology transfer and knowledge exchange processes with other institutions, enterprises			+	
	Increased ability to adapt to different consumer needs			+	+
	Developing close relationships with consumers			+	+
	Improving working conditions		+	+	
Compliance with regulatory requirements	Reducing the negative impact on the environment/increasing safety and usefulness	+	+	+	
	Compliance with regulatory requirements	+	+	+	

Product and marketing innovations are mainly reflected in the competitiveness of an enterprise, its market position, and demand for its products. At the same time, their role in improving the production and sales activities of an enterprise, as well as the organization of the work process, is insignificant. Product and marketing innovations are the only types of innovations through which Group 1 indicators (competitiveness, demand, and market share) can be improved.

Technological innovations can have a small impact on some indicators of other groups, in particular the reduction of time to respond to customer requests (Group 1) and improving working conditions for workers (Group 3). An interesting feature of organizational innovations is that their implementation can have a positive impact on a large number of studied indicators compared to other innovation types.

The next step in the study of the relationship between innovations and business performance is to prioritize the identified factors by ranking them by the innovations' impact on them. In practice, the real impact of innovations on Canadian enterprises will have its own peculiarities in each specific case. However, it is possible to highlight the general patterns characteristic of the vast majority of enterprises, having determined the totality of factors of innovation activity. For this purpose, it is relevant to consider research on scientific, technological, and innovative development in the world and Canada in particular (Wipo, 2022). The results of such research, reflecting the main motives of innovative activity of Canadian enterprises in various industries, are shown in Table 5.

Table 5 – Priority of Innovation Performance Factors (Other Than Organizational) According to the Study Conducted on the Basis of Canadian Enterprises

Factor in decreasing order of priority	**Percentage of surveyed enterprises**	**Group to which the indicator belongs**	**Innovation type**
Improving the quality of goods and services	38%	Production and sales policy	Technological, product
Expanding the range of goods and services	34%	Competitiveness, demand, market share	Product
Increasing or maintaining market share, entering new markets	29%	Competitiveness, demand, market share	Product, marketing
Increased flexibility in the delivery of goods and services	24%	Production and sales policy	Technological
Increased ability to supply goods and services	24%	Production and sales policy	Technological
Compliance with regulatory requirements	18%	Compliance with regulatory requirements	Technological, product
Reduction of labour costs	18%	Production and sales policy	Technological
Reducing the negative impact on the environment/increasing safety and usefulness	14%	Compliance with regulatory requirements	Technological, product
Reducing the cost of raw materials	10%	Production and sales policy	Technological, product
Other factors	<10%	×	×

It should be noted that the survey included innovation-active enterprises that implemented product, marketing, or technological innovations. Organizational innovations, as a result of their specificity, were placed in a separate group in this study. From Table 2 one can conclude that the main plane of innovation activity of enterprises in Canada is product and technological changes, because these types of innovations correspond to main factors of innovation.

The first three factors of innovation performance, defined by enterprises as the main ones are associated with revenue (income) from the sale of products. The quality and range of products are related to price parameters, and the market share is a reflection of the number of sold products. The impact of innovation on these characteristics was determined as 'most important' by 38%, 34%, and 29% of surveyed enterprises.

It is advisable to emphasize the fact that only a small part of enterprises in the study identified reductions in the cost of raw materials as an important effect of innovation activities. This can be explained by the fact that the level of technological equipment of most enterprises at the present stage is characterized by a fairly high level of energy and raw material efficiency, and therefore the

introduction of technological innovation in this direction can give only a small effect. At the same time, for Canadian businesses, the role of this factor in adding value and improving operational efficiency is one of the leading.

4 DISCUSSION

When studying the impact of innovations on enterprises' efficiency, researchers use a comprehensive approach to the analysis of the problem. They apply the method of comparative analysis and expert evaluations; methods of empirical research; interviewing; observation; expert survey; statistical data analysis.

These methodological recommendations do not take into account some important features of the development and implementation of new technologies. Increasing the effectiveness of innovative projects is achieved by analysing the possibilities of maximizing the results, the prospects of innovations, their feasibility, and the diffusion of technology (Reznik and Kourdova, 2013).

It is more appropriate to consider formation of modern basic methodological aspects of introducing new technologies. The identified trends can serve as a conceptual basis for the formation of ways of enterprises' innovative development in modern economic conditions (Ganushchak-Efimenko et al., 2020; Doroshenko et al., 2016).

Some researchers believe that the integration concept is most acceptable for the analysis of enterprises' innovative development. It considers an enterprise as a relatively stable, holistic, and independent socio-economic system of an open type, integrating the processes of production and sales (Salope and Mlikota, 2020).

Enterprises' innovative development depends on how the technological system of an enterprise is ready to accept this or that innovative task and correctly assess it. The perception of the innovation task can take the form of:

- recognition of innovations, when the production system is interested and prepared to implement them;
- rejection of innovation, when it contradicts the interests of an enterprise, or when the production system is not ready for its implementation, and the controlling subsystem lacks effective leverage (Balcerzak, 2009; Hustič, 2009; Colombelli et al., 2020).

The existing methods for assessing companies' innovative development are usually difficult to apply. A significant disadvantage of these methods is the lack of a systematic approach to the selection of evaluation indicators. The list of indicators proposed by different authors to solve the problem in question is quite significant, but they are usually not mutually coordinated and duplicate each other. The simplest methodologies, which use a small number of assessed indicators, do not allow for a comprehensive solution to this problem (Petrenko

and Karnaushenko, 2020; Ihnatenko et al., 2020; Gorączkowska, 2021; Nimer, 2016; Testa, Szkuta and Cunningham, 2019).

The research methods chosen in the present study give an opportunity to assess innovative sphere more objectively, as they give an opportunity to estimate the influence of factors which are difficult to predict. That makes it possible to make an in-depth analysis of the results and carry out predictive development.

It became clear that one of the prerequisites for the development of innovation in Canadian enterprises is the presence of entrepreneurial culture. According to modern global trends, it is formed in society by universities based on their interaction with enterprises.

Creating an innovative entrepreneurial environment in Canadian companies should include the following areas:

- Promoting the values of the knowledge economy and innovation as the foundation of modern Canadian entrepreneurship;
- Concentration and use of relevant knowledge about innovation and entrepreneurship based on active international interaction; intensification of interaction with all persons, groups of persons, and organizations interested in the activities of a university (stakeholders) and cooperation with enterprises;
- motivation and development of leadership and entrepreneurial qualities of future professionals by involving students in entrepreneurial and innovative activities during their studies at Canadian universities.

5 CONCLUSIONS

The results of this study are of practical importance for innovative areas of business, can be used as a basis for management decisions in enterprises. As for the scientific sphere, the methods of fuzzy logic have shown their rationality in decision-making in all forms of modern entrepreneurship.

According to the Global Innovation Index, Country RepTrak, and Global Sustainable Competitiveness Index (based on correlation and regression analysis of relevant factors for 55 countries according to 2019 reports), the paper identified a positive impact of national reputational characteristics on sustainable competitiveness of innovative development factors. This suggests that businesses/countries seeking a sustainable competitive advantage should focus resources on strengthening reputation in conjunction with their innovation development management.

The work substantiates a set of parameters, the impact of innovations on which determines the achieved effect of their implementation. These parameters are grouped into four groups: competitiveness of an enterprise, the share of the target

market, demand; production and sales policy; personnel and communication policy; compliance with regulatory requirements.

Based on the analysis of innovation activity factors, it was found that product and marketing innovations are mainly reflected in the competitiveness of an enterprise, its market position, and demand for products. Technological innovations are reflected in production and sales. Organizational innovations affect the very number of performance indicators of an enterprise, but their impact is weak compared to other innovation types.

However, in some cases, the introduction of organizational innovation is a prerequisite for the effectiveness of technological, product, or marketing innovation.

The study empirically confirmed the hypothesis that there is a direct relationship between the level of enterprises' innovation activity and their efficiency, according to the results of innovation activity ratings.

Business incubators and accelerators are among the key entities for financing and stimulating the development of small and medium-sized enterprises (SMEs) in Canada and around the world. Moreover, they are an effective tool for attracting not only financial resources, but also information capital and expertise, which are especially valuable for SMEs at the initial stage. At the same time, it should be noted that not all SMEs have a startup orientation, which means that business incubators and accelerators are only a partial solution to the problem of SMEs' financing. Therefore, it is necessary to introduce professional and university education programs to train specialists in small business management.

A large number of different types of risks and the complexity of their planning were the limitations of this study. The study results are of applied value, which shows a number of key factors influencing the formation of competitive advantages of different enterprises based on innovation in a knowledge economy.

To date, the problem of finding ways to combine innovation and enterprises' strategic development goals remains unresolved. In addition, an important issue remains the proper combination and integration of these factors in the interaction of large companies and startups. Today in the scientific environment there are works where this issue is considered separately for large companies and for startups. These and other problems indicate that further research is needed, which would be based on the ways, forms, and methods to increase innovation activity, taking into account the current conditions of economic development.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.