Degree of Standardization and Innovation Capability Dimensions as Driving Forces for Innovation Performance

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ABSTRACT

Purpose: In 2019, the International Organization for Standardization (ISO) published the first international Management Standard (MS) for innovation management, the ISO 56002:2019, following previous successful MS as ISO 9001 and ISO 14001. Within this framework, this paper discusses the relationship between the implementation of MS and the Innovation capabilities (IC) and Innovation Performance (IP) the company. In other words, the article analyses whether the greater degree of standardization (DS) in firms, combined with some IC dimensions, positively influence the IP of firms.

Methodology/Approach: As the number of ISO 56002 implementations is still not very high and it is not certifiable yet, a survey has been carried out considering the spanish certifiable homologue standard UNE 166002 combined with other ISO standards such as ISO 9001, ISO 14001, ISO-TS 16949, OHSAS 18001 and/or others. The suvey has been responded by 73 certified companies; and a further fuzzy set Qualitative Analysis (fsQCA) has been performed.

Findings: The paper confirms that at least three main dimensions of IC influence positively the IP, namely: strategy, market, and structure and network. It is also confirmed that the DS is clearly a positive contributor to a higher IP.

Research Limitation/Implication: The data are gathered in only one specific country, although it is one of the few that had national certifiable standards specifically developed for innovation management.

Originality/Value of paper: The main value of the article is to be one of the first ones to analyse, in any way, the impact of the degree of standardization (including or not the innovation MS as for instance the ISO 56002 or the UNE 166002) on the IC and IP of the company.

Category: Research paper

Keywords: innovation performance; innovation capability; fsQCA; management standards

1 INTRODUCTION

Innovation is a key factor of successful companies. Nowadays, there is no discussion about it, one must bear in mind the widely recognized contributions from the last century by the economist Schumpeter (1934) who pointed out the influence of innovation on economic cycles, or the competitive advantage of innovation (Porter, 1980), or the large set of models of innovation processes classified in five generations (Rothwell, 1994) and the Open Innovation concept (Chesbrough, 2003) among others. Empirical studies such as those by Prajogo (2006) demonstrate the importance of innovation performance (IP), understood as the results of the innovation process, for business performance. Thus, innovations create value by definition (Grandstrand and Holgersson, 2020).

Innovation capability (IC) can be understood as the potential to innovate (Saunila and Ukko, 2012), or the ability to continuously transform knowledge and ideas into new products, processes, and systems for the benefit of the company and its stakeholders. Furthermore, it is conceptualized as the ability to manage and integrate multiple key capabilities (Lawson and Samson, 2001) and resources of the firm to successfully stimulate innovation. Narcizo, Canen. and Tammela (2017) identified 19 different definitions for IP in the literature, concluding that the variability in descriptions of the term makes it difficult to build a unified definition. However, studies suggest that IC, as a construct of strategy, market, structure and network, innovation culture and project management, is found to be a key enabler for IP, which is, in turn, a key factor for business performance (Mir, Casadesus and Petnji. 2016).

Globalization needs effective collaboration within different actors around the world on innovation projects. Collaboration with external partners, suppliers and institutions are important for the IC of firms (Dziallas and Blind, 2019). Technology allows companies to build up innovation networking teams. However, collaborations must be managed properly to get efficient IP. In this context, the use of management standards (MS) is a relevant topic of study because having common frameworks of understanding between companies are supposedly beneficial for these collaborations and thus, for the innovation performance success.

Many studies have been carried out regarding the impact on business performance using MS, like ISO 9001 for quality management (QM) (Casadesus, Gimenez and Heras, 2001) or ISO 14001 for environmental management (Corbett and Kirsch, 2001), at national and cross-national level. However, when the analysis is focused on the impact of innovation MS on performance, the studies are limited to national scopes (Pellicer et al., 2008, 2014; Yepes et al., 2016; Mir, Casadesus and Petnji, 2016; Martínez-Costa, Jimenez-Jimenez and Castro-del-Rosario, 2019). There was no international consensus about how to manage innovation until when the ISO published the first international standard for innovation management, the ISO 56002:2019 "Innovation Management. Innovation Management System. Guidance".

Nowadays, there are more and more MS implemented in companies. Benefits and principles of management systems integration are also widely studied (Bernardo et al., 2015; Nunhes, Bernardo and Oliveira, 2019). The study of Hernandez-Vivanco et al. (2019) found that the ISO 9001 is the common factor of these combinations, and it is also the first standard adopted by most companies. These results would suggest that ISO 9001 might be a relevant driver towards improving business performance.

Therefore, ICs and the use of MS can be considered complementary antecedents of IP. For this reason, it is of paramount importance to not only understand the influence of each of the concepts on IP but also their combination to boost a firm's success. In other words, the main Research Question (RQ) of this article is which combination of ICs and degree of standardization (DS) are more likely to lead to a better IP of the firm? With this main objective, three specific RQ can be stated:

RQ 1: Innovation capabilities (IC) influence positively the innovation performance (IP)?

RQ 2: A higher degree of standardization (DS) impact positively on the innovation performance (IP)?

RQ 3: A combination of innovation capabilities (IC) with a higher degree of standardization (DS) boost innovation performance (IP)?

This study contributes to the literature in its orientation towards certified companies in its theoretical grounding and in its analysis procedures. First, the analysis of the combination of MS and innovation capabilities that explain better firms' performance is the study focus, rather than the solely impact of MS and innovation capabilities on IP that has been widely studied in the literature. Second, the study applies a Fuzzy-set Qualitative Comparative Analysis (fsQCA). fsQCA provides a platform from which to investigate combinations of all antecedents that would better explain the innovation outcomes. Third, this study also has a sustainability orientation in its choice of business outcomes. The results of the study may be a decisive argument for those business managers who question whether it is worth the effort of implementing MS as a complementary factor to their IC for the enhancement of the IP.

This paper is structured in the following manner. The first section is a literature review. The second section explains the methodology used including the sampling and data collection. In the third section, the results of the study are exposed. In the fourth section, the conclusions are described and, finally, the last section contains the discussion and further research proposals.

2 LITERATURE REVIEW

The most relevant literature related to this study is twofold. On the one hand, literature has been reviewed regarding IC dimensions and its influence on IP.

This is a necessary prior step to support the capability dimensions analysed in this study and its contribution to the relationship between IC and IP.

On the other hand, there is a state of the art in previous studies regarding MS and its influence on IP that must be considered because the results of this study will contribute also to this field of study.

2.1 Innovation Capability (IC) Dimensions and Innovation Performance (IP)

Studies on the relationship between IC and IP were performed previously in different perspectives. A literature review published on the relationships between IC, innovation measurement and IP at the firm level suggests that IC and measurement are multi-faceted constructs (Bayrle, Stein and Brecht, 2019), and states that this research area has become more diversified and innovation drivers have been emerging over time.

Dziallas and Blind (2019) analyzed scientific publications on innovation indicators published between 1980 and 2015 in which they identified 82 unique indicators to evaluate innovations. They found six company-specific dimensions (strategy, innovation culture, competence and knowledge, organizational structure, R&D activities and input, and financial performance) and three contextual dimensions (market, network, and environment) as enablers for innovative products, innovation process and innovation project management. However, their conclusions included that: "Despite the high number of well-known indicators and factors, concrete indicators to evaluate innovations are difficult to identify in the selected literature. Nevertheless, these factors are important because they have a positive or negative impact on the innovation outcome, depending on the identified publications" (Dziallas and Blind, 2019, p.16).

Similarly, Mir, Casadesus and Petnji (2016) not only identified, but also assessed and empirically confirmed five innovation capability dimensions (Project Management Process, Innovation Culture, Structure and Network, Market and Strategy). In fact, the variables used for the present study are adopted from Mir, Casadesus and Petnji (2016), which in turn were inspired by Lawson and Samson (2001) and Saunila and Ukko (2012) models and based on the standard CWA 15899 (CEN, 2008).

Studies on the relationship between IC and IP are paramount for the theoretical framework in this study. Therefore, a literature review on this topic is presented in Table 1.

Table 1 – Literature Review Summary on IC and IP

Author	**Main objective**	**Method**	**Sample**	**Main findings**
Saunila (2014), Saunila, Pekkolo and Ukko (2014)	Study the relationship between organizational IC and firm performance.	Survey in Finland.	311 SMEs employing 11-249 persons and having a revenue of two to 50 Meuro.	Three aspects found: ideation and organizing structures, participatory leadership culture, and know-how development. The three aspects influenced the financial performance more than the operational.
Rajapathirana and Hui (2018)	Investigated the relationship between IC, innovation type and firm performance, including IP.	Survey in Sri Lanka.	379 senior management of insurance companies.	IC has direct and positive impact on the product, process, marketing, and organizational innovations, and stimulates the IP through innovation efforts. Furthermore, IP implies higher market and financial performance.
Oanh (2019)	Assess the impact of IC on types of innovation and innovation performance in foreign direct investment enterprises.	Survey in Vietnam	254 foreign direct investment enterprises in Vietnam.	Positive relationship between IC and IP mediated by four types of innovation (organization, product, process and marketing) in the scope of foreign direct investment firms, suggesting that improving IC affects corporate culture towards IP.
Wang and Hu (2020)	Reveal the mechanisms of collaborative innovation processes by investigating the relationships among critical factors influencing firm's IP in supply chain networks.	Survey in China	236 firms	Significant positive relationships were found between collaborative innovation activities, knowledge sharing, collaborative IC, and firm's innovation performance. Collaborative IC shows a moderating effect on the innovation process.

Notes: IC – Innovation Capability, IP – Innovation Performance.

The literature confirms the positive relationship between IC and IP in many studies. Some consider types of innovation as mediating factors (Rajapathirana and Hui, 2018; Oanh, 2019). Others focused on moderator factors, such as measurement (Saunila, Pekkolo and Ukko, 2014). Saunila (2014) centered studies on the relevant aspects of IC namely ideation and organizing structures, participatory leadership culture, and know-how development. Mir, Casadesus and Petnji (2016) analyzed the IC dimensions in five construct variables, project manager process, innovation culture, structure and network, market and strategy. Wang and Hu (2020) suggest collaborative innovation activities, knowledge sharing and IC as the three key factors that jointly shape IP.

2.2 Management Standards (MS) and Innovation Performance (IP)

Literature on Management Standards (MS) are especially extensive regarding Quality Management (QM) disciplines, in which the ISO 9001 is the most studied globally. They are studied in terms of benefits and drawbacks in many perspectives, such as internal and external benefits (Casadesus, Gimenez and Heras, 2001; Casadesus and Karapetrovic, 2005). Integration benefits within other standards are studied (Bernardo et al., 2009), ISO 9001 quality system certification and its impact on product and process IP was also studied in Australia (Terziovski and Guerrero, 2014) among others, ISO 14000 is also studied widely (Corbett and Kirsch, 2001). Several MS implementations such as ISO 14001, ISO 9001, OHSAS 18001, ISO 27001 and SA 8000 are also studied focusing on integration scope, sequence and time of implementation (Karapetrovic and Casadesus, 2009).

Studies on standardized innovation management systems (SIMS) have been studied, focusing on national innovation standards such as the Spanish UNE 166002 (AENOR, 2006). Studies in the SIMS construction sector are focused on implementation case studies (Pellicer et al., 2008, 2014; Yepes et al., 2016) and further empirical studies in many sectors studied the impact of SIMS on business and IP (Mir, Casadesus and Petnji, 2016). Martinez-Costa, Jimenez-Jimenez and Castro-del-Rosario (2019) found that implementing the SIMS promotes all types of innovations and their results found a positive relationship between administrative and technological innovation. Hernandez-Vivanco et al. (2019) studied the combinations of different MS and found that the ISO 9001 is the common factor of these combinations. It was found to be the first standard adopted by most companies while suggesting that it might be a relevant driver towards improving business performance. A case study examined the standardization effort as a complex codified knowledge (Xie et al., 2016) concluding that more codified knowledge implies more incremental and architectural innovation outcomes but less modular and radical innovations. Sahoo (2019) examined the relationship between QM, IC and firm performance under mediation and moderation models using data from 134 Indian SME manufacturing firms, they found that QM through the firm’s IC is indirectly associated with a firm’s business performance as QM practices encourage the definition of innovation strategies of products and processes.

Although some studies investigate the impact of MS on the IP, such as quality MS (Hernandez-Vivanco et al., 2019) and innovation MS (Mir, Casadesus and Petnji, 2016; Martinez-Costa, Jimenez-Jimenez and Castro-del-Rosario, 2019), none of the studies detected answers to the question of whether the DS is a relevant factor in combination with IC to positively influence IP. Furthermore, neither of these studies answer the question regarding which of the IC dimensions of the construct in combination with others are more relevant in this influence. Thus, this study aims to fill this gap in the knowledge as an unprecedented contribution to the literature in this field. No contribution has been detected that answers the questions of whether the DS in combination with

IC influence IP, or which of the IC dimensions of the construct combination are more relevant in this influence.

3 METHODOLOGY

3.1 Sampling and Data Collection

A specific questionnaire was designed for the research line of this paper. The questionnaire had four sections. Apart from the first and second sections (demographic characteristics of the respondent and firm's descriptive data), the rest of the questionnaire was based on standards and guidelines, namely UNE 166002 (AENOR, 2006), CWA 15899 (CEN, 2008), EFQM Framework for innovation (EFQM, 2005), Oslo Manual (OECD, 2005) and the Community Innovation Survey (CIS, 2010).

The firms that received the questionnaire were selected through a random sampling method. In total, one thousand questionnaires were sent by post to Spanish firms. The final number of responses collected was seventy-three after rejecting incomplete questionnaires. Most of the questionnaires were answered by the R&D Director (44%), the Technical Manager (29%) or the General Manager (15%) of the firm. Once the answers were collected, a Harman's single factor test was performed to assess common method bias in the responses. No bias was detected.

3.2 Method

Because the interest of this research is to understand, on the one hand, the impact of innovation and DS on business performance and, on the other hand, the impact of their combination, this study uses qualitative comparative analysis (QCA) because this method explores which combinations (or configurations) of determinants (or antecedents' conditions) are sufficient to explain the outcome. QCA assumes causal complexity because uses Boolean logic rather than traditional correlation methods to set causal conditions related to a particular outcome (Ragin, 2008). Due to this capability, QCA has become an attractive technique in the field of management. The perspective of QCA produces better managerial conclusions because permits to conduct more fine-grained analysis of the antecedents that explain better the outcome (Rasoolimanesh et al., 2021).

According to Berbegal-Mirabent and Llopis-Albert (2016), QCA is appropriate when the analysis is based on a small data sample and the conclusions and implication may be generalized to larger populations.

Since QCA can only compute binary variables, the authors applied fsQCA (fuzzy set Qualitative Analysis) that permits the incorporation of continuous variables as antecedents or outcomes. In the study, the software used was fsQCA 3.0 (Ragin and Davey, 2016).

3.3 Measured Factors

Based on the above review of the literature regarding IC factors (Saunila, 2014; Mir, Casadesus and Petnji, 2016; Wang and Hu, 2020) and standardizing effort (Xie et al., 2016), and considering the stated hypotheses, six determinants were explored in the present study. On the one hand, the five innovation capability dimensions adopted from Mir, Casadesus and Petnji (2016): Project Manager Process (PMP), Innovation culture (ICULT), Structure and Network (STRU), Market (MARK) and Strategy (STRA) and, on the other hand, the antecedent DS that computes the number of MS implemented in the firm.

Table 2 presents the main descriptive statistics and the factor loadings of the variables that compose the underlying innovation capability dimensions, resulting from the five principal component analysis conducted, using varimax rotation. All the variables are based on a 4-point scale (ranging from 1: totally disagree to 4: totally agree). Most of the loading values are over the recommended cut-off level of 0.6 indicating a good convergent validity. In addition, Table 2 includes the indices of internal consistency (Cronbach's alpha and Average Variance Extracted) of each dimension. Both values are also over the recommended cut-off levels of 0.7 (Nunnally and Bernstein, 1994) and 0.5 (Fornell and Larcker, 1981) and, therefore, the internal consistency of the five innovation capability dimensions are validated.

Table 2 – Descriptive Statistics and Validity of the Innovation Capability Dimensions

	Descriptive statistics		**Principal component analysis**	
	Mean	**St. Dev.**	**Load.**	**Internal consist.**
Project Management Process (PMP)				
C4: Innovation project risks are controlled systematically using methods and tools such as DAFO analysis, etc.	2.63	0.98	0.804	α: 0.765 AVE: 0.685
C27: Innovation projects are nearly always carried out on planned time and budget schedules	2.67	0.80	0.845	
C28: Clearly defined and precise criteria are used to evaluate and select potential projects for implantation	2.89	0.85	0.835	
Innovation Culture (ICULT)				
C3: Management bodies demonstrate high willingness to engage in new ventures (openness to new markets and technologies, etc.)	3.23	0.87	0.828	α: 0.789 AVE: 0.618
C7: Employees are free to present ideas or suggestions at any time	3.56	0.72	0.793	
C15: Capability exists for employees with different backgrounds to work together in innovation project teams	3.28	0.72	0.787	
C29: Project team members treat one another with trust and respect	3.43	0.55	0.736	

	Descriptive statistics		Principal component analysis	
	Mean	**St. Dev.**	**Load.**	**Internal consist.**
Structure and Network (STRU)				
C11: A budget is allocated for innovation projects that is not directly funded by customer orders	2.97	0.94	0.826	α: 0.816 AVE: 0.736
C16: External business partners who meet the particular project requirements are sought	3.46	0.78	0.854	
C17: Correspondence with external research sources is maintained to remain aware of relevant technological and research developments	3.26	0.85	0.894	
Market (MARK)				
C18: Relationships with customers, suppliers, etc. are maintained in anticipation of future market needs	3.10	0.75	0.823	α: 0.859 AVE: 0.592
C19: To meet future demands, customers are included in the entire process of product/service development	2.93	0.80	0.799	
C20: Feedback such as complaints and suggestions are systematically reviewed and acted upon	3.02	0.72	0.840	
C33: Through innovation, the company has acquired greater market shares than its competitors	2.83	0.83	0.759	
C35: As part of the innovation process, market-oriented distribution channels are identified at an early stage	2.54	0.78	0.637	
C36: By taking into account various factors throughout the product development process, a diverse range of products is produced	2.63	0.82	0.743	
Strategy (STRA)				
C12: Innovation projects are based on the general company strategy	3.15	0.81	0.791	α: 0.904 AVE: 0.635
C21: Excellent knowledge on the competitive market environment	2.91	0.75	0.782	
C22: Precise definition creation in advance of developing tasks and goals	2.78	0.80	0.844	
C23: Communication of information needed for innovation projects is exceptionally frank, transparent and honest	2.97	0.76	0.820	
C24: Mistakes made during innovation projects are viewed as opportunities to systematically learn and improve	3.24	0.77	0.802	
C30: The innovation vision is considered during strategic decision-making	3.23	0.84	0.774	
C31: Innovation projects follow a documented innovation process that considers all areas of activity	3.10	0.79	0.765	

To compute the number of MS implemented, the respondents had to select from a list of the five most implemented MS in Spain: ISO 9001, ISO 14001, ISO-TS 16949, OHSAS 18001, UNE 166002 (Mir, Casadesus and Petnji, 2016). Moreover, there were the options of 'none' and 'others'. Table 3 presents the main and the standard deviation of the number of standards implemented. The authors also considered it necessary to include, as antecedent, the categorical variable 'size' to control the configurations by the size of the firm. The respondent had to choose between three options in the questionnaire: large, medium, or small size. However, in this study, firm size is transformed into a clear set with 0 denoting SMEs and 1 denoting large firm (+ 250 employees).

Finally, the output of the analysis (innovation performance) was measured with the percentage of firm's turnover due to innovations with less than three years in the market. The respondent had to select one of the next three options: the percentage had reduced, maintained, or increased in the period 2007 to 2011. Table 3 presents the main descriptive statistics of 'degree of standardization', 'size' and '% turnover innovation'.

Table 3 – Descriptive Statistics of Degree of Standardization, Firm Size and Turnover Innovation

	Mean	**St. Dev.**
Degree of standardization (DS)		
Number of management standards implemented in the firm (1 – 7)	2.47	1.38
Size (SIZE)		
Size of the firm	SMEs: 68,5%	
	Large: 31.5%	
% Turnover innovation (TURNINN)		
% of turnover due to innovations with less than three years in the market	Increased: 37%	
	Maintain: 52%	
	Reduced: 11%	

4 RESULTS

Three steps are necessary to apply fsQCA method. First, the calibration of outcome and antecedent conditions into fuzzy sets. Second, the construction of the truth table and, finally the reduction of the number of rows in the truth table for obtaining the combinations that explain the outcome. Following Ragin (2008), the calibration procedure was applied in all the antecedents, except for the binary variable 'firm size', and the outcome. Two anchors are defined denoting full membership (fuzzy score = 0.95) and full non-membership (fuzzy score = 0.05).

Next, the truth table is constructed based on a matrix space with 2k rows, where k is the number of antecedent conditions. Table 4 presents the truth table. None of the antecedents is higher than the cut-off level of 0.90 and, consequently, none of the antecedents is a necessary condition to produce the outcome (Schneider, Schulze-Bentrop and Paunescu, 2010). Therefore, all the antecedents are included in the fsQCA.

Table 4 – Truth Table

	Consistency	**Coverage**
PMP	0.623744	0.725786
~PMP	0.581120	0.755001
ICULT	0.601205	0.711757
~ICULT	0.569516	0.726031
STRU	0.646507	0.745305
~ STRU	0.538049	0.706417
MARK	0.627092	0.798976
~ MARK	0.602321	0.713455
STRA	0.626199	0.741543
~ STRA	0.565275	0.720421
DS	0.624191	0.680370
~ DS	0.517072	0.726560
SIZE	0.316224	0.616087
~ SIZE	0.683776	0.612800

Notes: PMP – Project Management Process, ICULT – Innovation Culture, STRU – Structure and Network, MARK – Marketing, STRA – Strategy, DS – Degree of Standardization, SIZE – Size of the company.

Table 5 presents the results of the fsQCA. Following Ragin's (2008) recommendation, an intermediate solution was selected to interpret the results. We followed the notation proposed by Fiss (2011). The presence of a condition is represented by a full circle (●) while an empty circle (o) represents its absence, whereas ambiguous (unclear) conditions are represented by blank cells. Moreover, large circles indicate that a condition is core to a given configuration, while small circles point to a peripheral role. A condition is considered core when it has a strong causal relationship with the outcome of interest while a condition is peripheral when it has a contributing role.

Table 5 – Sufficient Configurations of Antecedent Conditions for % Turnover Due to Innovation

Configuration	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
PMP			O	•	o	o	o	o	•	•	•	•	o	•		O
ICULT	•	•	O	o	•	•	•	o	o	•		•	●	•	O	
STRU	•	•	O		o	o			o		•	●	•	o	O	O
MARK		●	•	o	o	•	•	o		o	O	•	o	o	O	O
STRA	●	•		o	o	o	o	o	o	•	•	•	o	•	O	O
DS	•	•	O	•			o	o	•	•	•		•	o	•	•
SIZE	•		O	o	•	o	o	•	●	•	•	o	o	o	•	•
Raw coverage	0.148	0.292	0.136	0.127	0.069	0.111	0.108	0.064	0.064	.0120	0.135	0.224	0.094	0.072	0.068	0.066
Consistency	0.752	0.865	0.893	0.896	0.945	0.860	0.875	0.954	0.912	0.937	0.951	0.794	0.976	0.805	0.947	0.942
Solution coverage	0.667															
Solution consistency	0.814															

Notes: PMP – Project Management Process, ICULT – Innovation Culture, STRU – Structure and Network, MARK – Marketing, STRA – Strategy, DS – Degree of Standardization, SIZE – Size of the company.

Table 5 also includes the measures of consistency and coverage for the multiple solutions as a whole and each of the configurations. Consistency and coverage are the measures for validating the solutions (Ragin, 2008). “Consistency refers to the degree to which cases that share a combination of conditions consistently produces the key outcome” (Campbell, Sirmon and Schijven, 2015, p.22) while “overall coverage describes the extent to which the outcome of interest may be explained by the configurations” (Pappas, Giannakos and Sampson, 2016, p.49).

The higher the raw coverage value of a configuration is, the more relevant the configuration is since that configuration covers a higher proportion of cases (Olaya-Escobar, Berbegal-Mirabent and Alegre, 2020). Results of fsQCA indicate an intermediate solution with a solution coverage of 0.667 and a solution consistency of 0.814. The existence of multiple configurations suggests that no unifying causal path can explain the outcome. In fact, sixteen possible configurations appear with a raw coverage between 0.064 and 0.292 which means that the causal models are sufficient, but not necessary according to Ragin (2008).

Next, the obtained results are analysed following the recommendation of Ragin (2008). Firstly, it is assessed the solution table, focusing the attention on configurations #2 and #12 that deserve further attention since they have the highest values of raw coverage, both over the cut-off level of 0.2. However, it has been also decided to include in the analysis the next configuration with higher raw coverage (#1) since gave us the opportunity to assess the role of the size of the firm to explain the outcome. Secondly, it is analysed each of the antecedent conditions for all the configurations.

The results reveal that, in the two most important configurations #2 and #12, at least one of the IC dimensions is present as a core condition. Specifically, MARK, and STRU respectively. In fact, whether it is included in the analysis configuration #1, almost all the IC dimensions are present in the three configurations. Only PMP is not present in configurations #1 and #2, nor MARK in configuration #2 either. Therefore, it appears that, in general, all the IC dimensions are important to boost IP.

The DS is present in configurations #1 and #2. However, it is always present as peripheral condition in the rest of configurations. These results would confirm its importance for boosting IP in any configuration but in a lower manner compared with IC dimensions. In addition, considering the three main configurations, it seems that this global perception is suitable for any size of firm since there is no consensus.

When the analysis is focused on each antecedent, different findings are obtained. The IC dimension that explains more IP is ICULT, in line with Oanh (2019). This evidence suggests improving IC impacts corporate culture towards IP, since it is present in nine out of sixteen configurations. This finding would suggest that culture is a highly transversal factor. In contrast, STRA is the dimension with less presence. The number of MS implemented is also present in most of the configurations, confirming the global analyses obtained previously. Again, there is not a clear consensus about the relationship between the size of the firm and IP.

5 DISCUSSION AND CONCLUSIONS

IC is of paramount importance of study because it is present as a core antecedent for IP enhancement (Mir, Casadesus and Petnji, 2016; Oanh, 2019; Wang and Hu, 2020). Six dimensions of the IC construct are analysed in this study, in combination with the DS, to draw on this field of knowledge in a deeper detail and to provide an unprecedented contribution to the literature in the field.

The results obtained are in line with previous studies, thus confirming that IC influence positively the IP of firms as, at least, one of the core conditions in the three configurations with the higher row coverage values are IC dimensions, namely: strategy, market, and structure and network. Moreover, almost all the IC dimensions are present in the three configurations. Therefore, the first specific research question is positively contrasted.

Another relevant result is that, although the DS is not a core condition in any configuration, it is present in most of the configurations as a positive contributor antecedent. This result would confirm previous studies about the importance of the MS for seeking a better performance. In line with Casadesus, Gimenez and Heras (2001), these results suggest that MS cover most of the processes of firms, including firm innovation processes. Therefore, the second specific research question is also positively confirmed.

Finally, the results confirm the complementary coexistence of DS and IC to boost IP in most of the configurations. In addition, it seems that this coexistence is suitable for any size of firm since there is not a clear pattern of size among the configurations. For instance, the most relevant configuration (#2) represents any size of firm skilled with a close relationship with stakeholders to anticipate future market needs through including their demands in the process development of products with costumers or taking account their concerns, among other market actions. On the other hand, configuration #12 exemplify small firms that their most important IC is their structure and network. Unlike configuration #2, the DS in configuration #12 does not explain a better IP.

Therefore, the main theoretical conclusion of the present study is that further studies should consider the DS of firms as it is found to be an important antecedent factor complementary to IC for IP, at is has been demonstrated to be a transversal contributor.

Our study also offers important insights to managers. It can be concluded that it is worthy to invest on implementing MS because the effort of the implementation will have a payback. A higher DS in a transversal manner will be an excellent complementary factor to the IC of the firm, in order to improve the IP, and, in turn achieve a better business performance.

This is coherent with the innovation culture factor results, that is found to be the highest contributor IC dimension to improve IP in all the configurations, suggesting that both culture and standardization are transversal and positive for IP.

Finally, for the policy makers, the conclusion is apparent as this study highlights the benefits of the standardization. Consequently, policy makers should give further support to develop standardization policies, as is the case of the ISO that is currently developing the next innovation management system standard requirements ISO 56001 by the ISO/TC 279 technical committee. Overall, it can be concluded that the more DS contributes positively as a complement of IC in boosting IP.

6 LIMITATIONS

Regarding the limitations of the paper, the first one is that the data is gathered in only one country, Spain, but in that moment, it was one of the few countries that had national certifiable standards specifically developed for innovation management that allowed gathering data. Thus, beyond the most common standards such as QM (ISO 9001) and environment management (ISO 14001) among others, today it is difficult to perform cross-national analysis including standards for innovation management, as it is not possible to include ISO standards on innovation management because the ISO standards for innovation management that are published today, such as ISO 56000, ISO 56002, ISO 56003, ISO 56008, among others, are not certifiable standards, and data cannot be gathered.

Future research should explore other perspectives focused on MS to discover which of the different standards contribute more on IP and business performance outputs, not only the number of MS implemented are important as studied in this paper but also which of them are more important inputs for IP enhancement output. In addition, it would be interesting to perform the same analysis but with the absence of IP to understand the asymmetric role of these antecedents.

Also, it would be interesting to include in the future analysis the impact of the implementation of the ISO 56001 standard because it will be the first certifiable international standard for innovation management. Finally, future research should perform the present analysis in other regions to conduct cross-national analysis and control the influence of other contextual variables.

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Conceptualization, M.C., MM. and J.L.; Methodology, M.M.; Validation, M.M. and J.L.; Investigation, M.M.; Original draft preparation, J.L.; Review and editing, M.C.; Supervision, M.C.

CONFLICTS OF INTEREST

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A Comparison of the Development of Selected Macroeconomic Indicators of the Regions of the V4 Countries

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ABSTRACT

Purpose: The purpose of the article is to compare a degree of beta-convergence between V4 countries and EU28 at national and NUTS 2 level.

Methodology/Approach: We will make this comparison separately for each indicator (gross domestic product at current market prices, unemployment rate and disposable income of households.). To evaluate beta-convergence differences at national and regional level, we will compare the data for the V4 countries and for Germany and Austria. To show convergence, we approximated the GDP growth trend in individual countries, using a trend line for three different time periods.

Findings: Our results point to persistent disparities between regions. They have confirmed that the cohesion policy in the regions of the V4 countries should promote innovations and investments into less developed and predominantly agricultural regions, complete the necessary backbone infrastructure and develop a high-quality regional education. At regional level, the implementation of high value-added programs may be hampered by institutional factors and a lack of capacity to make the necessary infrastructure or human capital investments. Our analysis showed that differences in regional performance are also accompanied by significant differences in investigated indicators.

Research Limitation/Implication: Limitations of the paper are at first missing data for Poland to the year 2013. Second limit of the article are data from regions, because data are related to the palce of residence of its branch.

Originality/Value of paper: Paper is full original,also a data analysis does not copy any other articles neither article in a journal nor paper on conference.

Category: Research paper

Keywords: V4 countries; NUTS 2 regions; cohesion policy

1 INTRODUCTION

The Visegrad Four (hereinafter as V4) (Czech Republic, Slovakia, Poland and Hungary) form a relatively homogeneous unity within Europe with many cultural-historical and economic similarities. They all began the process of economic transformation from a planned economy to a market economy in the early 1990s and became members of the European Union in 2004 once they completed this process.

During the switchover to a market economy, the V4 countries gradually converged, with different intensity over time, towards more advanced economies and their growth usually exceeded growth achieved in the old EU Member States because their initial growth was low, a so-called beta-convergence (Barro and Sala-i-Martin, 1992). Beta-convergence is a process in which countries considered less developed show a long-term higher value of a selected indicator than developed countries. In our article, we use it to compare the GDP of the analyzed countries.

However, the development of economies as a whole may not fully reflect the economic and social situation of all citizens or industries. It turns out that there may be significant differences across the regions of the V4 countries, which continue to deepen over time (see, for example Kuttor, 2009), thus reducing the overall economic growth potential. A comparison at country level may not reveal such development and may provide a distorted picture that may lead to exaggerated optimism in assessing the convergence and effectiveness of the economic policy. Deepening interregional differences may indicate that, despite the convergence of economies as a whole, there may not be a sigma-convergence at NUTS 2 level (Young, Matthew and Levy, 2008), signaling a gradual decrease in heterogeneity across regions in terms of income distribution and other macroeconomic indicators.

There may be several explanations for such development, but the main factors seem to be the previous high dependence of the regions on a single industry. In the era of a centrally planned economy, the necessary diversity was not promoted in the long term, administrative activities were concentrated in a single strong center and regional differences were part of the central plan (Dluhoš, Gajdoš and Hajduová, 2019). Many regions thus remained dependent almost exclusively on agriculture, mining and quarrying or on outdated heavy industry, which was not very competitive compared to developed countries after the switchover to a market economy. Its competitiveness continued to decline with the advancing convergence of employees' income, as it lagged behind in labor productivity growth and in the modernization of operations. Due to an insufficient transport and education infrastructure, low labor mobility and an underdeveloped tertiary sector, the regions concerned were not able to adapt as quickly as the regions close to the dynamically developing main centers. The identification of regional disparities and their detailed analysis is important for evaluating the effectiveness of the cohesion policy aimed at the development of economically weaker regions in the EU. The EU has made the cohesion policy one of its main objectives and secures it through a series of interrelated funds (European Commission, 2015). Although some selected regions in the older EU Member States (southern Italy, selected regions of Spain and others) also receive money from these funds, the main recipients are naturally regions in the new EU Member States. The purpose of the cohesion policy is to reduce income inequality between regions, to increase social inclusion and to accelerate investments in selected regions in order to increase regional innovations and labor productivity (Widuto, 2019). The main areas that are the focus of this policy include transport infrastructure, business and competitiveness support, education, science and research and investments into energy supply and the environment (Kokocinska and Puziak, 2018).

Literature is not fully conclusive on the real effectiveness of the cohesion policy. There are studies that find empirical support for its effectiveness (for example Venables and Gasiorek, 1999; Leonardi, 2006; Bradley and Untiedt, 2007; Di Cataldo and Monastiriotis, 2020), while the conclusions of other authors (Boldrin and Canova, 2001; Dall'Erba and Le Gallo, 2008) are rather skeptical or negative. Fratesi and Wishlade (2017) or Crescenzi, Fratesi and Monastiriotis (2017) point out that it is very difficult to evaluate effectiveness and suggest focusing mainly on the factors that can increase the effectiveness of the cohesion policy. Based on the performed analyses, they recommend making only specific investments in individual regions that correspond to several predetermined priorities. The outputs of our study may help to better target and streamline the above-mentioned tools of the cohesion policy in the regions of the V4 countries or to support the choice of their optimal mix. The right investments made as part of the cohesion policy can then help to increase the economic potential of the whole country and to accelerate convergence toward the advanced core of the EU.

2 METHODOLOGY

In this article, we empirically assess the extent to which heterogeneity across the regions actually persists and which V4 countries are the worst off in this regard. For these purposes, we compare the regions of the V4 countries at NUTS 2 level in terms of several different macroeconomic indicators. These are Gross Domestic Product at current market prices (in Purchasing Power Standard (PPS)) per capita (hereinafter as GDP), Unemployment Rate (in %, hereinafter as Unemployment rate) and Disposable Income of Households (in PPS) per capita (hereinafter as Disposable income) The goal is to find regions with similar economic characteristics and to group them, based on the cluster analysis, into homogeneous and economically interpretable groups. Since we have data in the form of time series, we are also interested in the dynamics of these quantities over time and in its impact on the increase or decrease of heterogeneity between the regions. We will make this comparison separately for each indicator, then we will group similar regions into four clusters according to all analyzed indicators. To evaluate convergence differences at national and regional level, we will first compare the data for the V4 countries as a whole and then for the entire EU and for our closest neighbors – Germany and Austria.

2.1 Data Source and Processing

The initial data for our analyses come from the Eurostat database. The entire analysis of all investigated quantities (GDP, Unemploment Rate and Disposable Income of Households) was performed in MS Excel and in Statgraphiscs Centurion 18. We used basic statistical functions and procedures to calculate the descriptive characteristics. The cluster analysis draws on hierarchical clustering with Ward's method (Johnson, 1967). It merges clusters with the minimum sum of squares. The method is based on the loss of information that occurs during clustering. The clustering criterion is the sum of squared deviations of each object from the centeroid of the cluster to which it belongs. The distance of individual objects is measured based on squared Euclidean distance. The goal is not to optimize distances between clusters but to minimize cluster heterogeneity based on the criterion of minimum increment of the intragroup sum of squared deviations of objects from the centeroid of clusters. In each step, the increment of the sum of squared deviations, created by their merger, is calculated for all pairs of deviations and then clusters corresponding to the minimum increment are merged.

The main output of the cluster analysis are dendrograms that we will display for the given data. We will try to divide the regions into 4 homogeneous clusters. These clusters should be easily identifiable from the dendrogram output. The cluster analysis should confirm the conclusions from the analysis and descriptive characteristics of data.

The data are compared for territorial units according to the NUTS 2 classification (CZSO, 2020; Eurostat, 2020a). All analyzed data come from the Eurostat database. However, there is a problem with data availability because all three analyzed indicators by region are not available for the same time period in all four countries. GDP per capita in USD at purchasing power parity is published by the V4 countries for the years 2000-2017, with the exception of Poland that only provides data for the years 2014-2017. All four countries publish the general unemployment rate at NUTS 2 level for the years 1999-2018. Poland publishes household income only for the years 2014-2016, other countries publish it for the years 2008-2016. This somewhat complicates the analysis of regional differences over time, but we always try to make comparisons over the longest possible time period. For the analysis of convergence at the level of the entire economy, there is generally no problem with data for Austria and Germany, but data for the entire EU or for some of its parts (Eurozone) are not always available. This will, of course, be reflected in some of the comparisons below – both in tables and figures.

To show convergence, we approximated the GDP growth trend in individual countries, using a trend line in the form $y = ax + b$, where a represents an estimated GDP growth trend. We approximated the trend line both for the entire analyzed period and for different time periods – the period of growth (2000-2007), the period of crisis (2008-2012) and the period of economic recovery after the crisis (2013-2017).

3 RESULTS

The results obtained from the analyses are divided into three areas, where we compare the impact of the following factors on regional heterogeneity:

- GDP at current market prices (in USD),
- Unemployment rate,
- Disposable income of households (in USD).

3.1 Gross Domestic Product at Current Market Prices

Due to different prices in the countries, we converted GDP per capita based on purchasing power parity. Let's first see what the comparison of individual countries looks like. We compared all countries, although data for Poland on the Eurostat website are available for 4 years only (2014-2017). Even so, Figure 1 provides an interesting comparison.

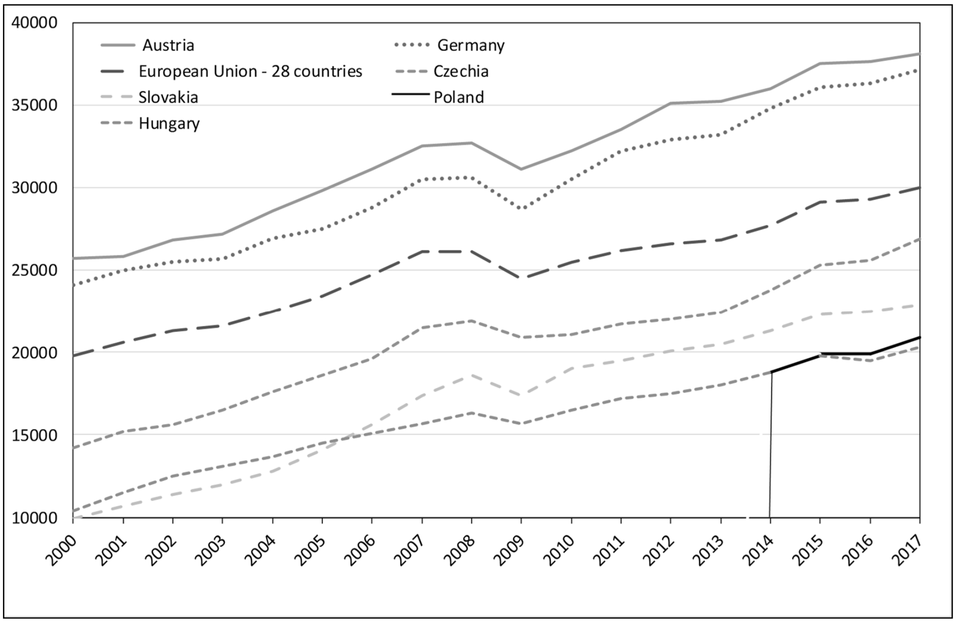

Figure 1 – GDP at Current Market Prices

At first glance, it is clear that the old EU Member States (Austria and Germany) continue to achieve significantly higher economic performance. Among the V4 countries, the Czechia shows the highest economic performance. It is followed by Slovakia and far behind Slovakia by Poland and Hungary. Overall, it is clear that convergence towards the EU's most developed countries is not fast enough to reach a similar economic level in the next decades. All V4 countries are at least converging toward the performance of less developed Western countries and the EU's economy as a whole. However, with respect to faster convergence toward the EU's economy, it is necessary to take into account the gradual enlargement of the EU for less developed countries. Table 1 shows that the speed of convergence towards more developed countries slowed down in the last years of the analyzed time period and indicates the need for stimulus measures to increase the growth potential of the V4 economies. We used linear regression to show the trends. In Table 1, a represents the slope of a line (trend) and R^2 represents the coefficient of determination of the calculated trend estimate.

Table 1 – Analysis of the GDP Trend in the V4 Countries and Selected Economies

Country	**The whole period**		**Boom 2000-2007**		**Crisis 2008-2012**		**Recovery 2013-2017**	
	a	R^2	a	R^2	a	R^2	a	R^2
EU28	554.80	0.9431	854.76	0.9662	270.00	0.2732	800.00	0.9484
Czechia	674.51	0.9431	990.48	0.9755	100.00	0.1033	1,080.00	0.9627
Slovakia	801.24	0.9693	1022.60	0.9584	510.00	0.6270	600.00	0.9375
Hungary	534.47	0.9771	734.52	0.9833	390.00	0.7341	530.00	0.8702
Poland	No data	No data	No data	No data	No data	No data	690.00	0.8924
Germany	761.61	0.9692	845.24	0.9496	810.00	0.6104	930.00	0.9260
Austria	753.04	0.9677	1006.00	0.9629	720.00	0.5781	740.00	0.9145

Notes: Data for Poland's GDP are available in the Eurostat database starting from 2014 only. Therefore, the trend estimate is calculated only for the years 2013-2017.

The analysis of the data from Table 1 shows that long-term beta-convergence between the V4 countries and the EU28 average concerns only Slovakia and the Czechia, where the trend line slope for the entire time period is higher than the trend of the EU28 average (first column in Table 1). These values also show greater dynamics of development in the Slovakia, both during the period of growth (2000-2007) and the period of crisis (2008-2012). During the crisis, Hungary showed dynamics similar to Slovakia's dynamics in terms of diminishing differences in the concept of beta-convergence. During the years 2013-2017 only the Czechia shows a faster development than the EU28. On the other hand, other V4 countries fell short, as Poland's growth rate lagged behind the EU28 by at least 14 percentage points.

Just for the record, we can estimate, based on the current trends, when the V4 countries will reach the level of the EU28 (we made a comparison to estimate trends for the entire analyzed period). It will take Slovakia 42 years and the Czechia 48 years. Hungary will never reach it – the trend line has a lower steepness than that of the EU28. The reliability of the trend estimate during the crisis is very low, as the GDP of all countries first dropped in 2009 and then gradually went up. In this respect, the Czechia was affected by the crisis the most.

A closer look at the GDP trend at regional level (Eurostat, 2020b) suggests that one of the reasons for the low growth potential may be the lagging behind of poorer regions, whose performance is growing too slowly compared to administrative and economic centers.

The capital cities (as separate regions) with the highest GDP took the first three places, while the remaining regions lagged way behind. CZ01 Praha and SK01 Bratislava had a very similar GDP and swapped places during the last two years of the analyzed time period. They were followed by HU11 Budapesť at a considerable distance. PL09 Makroregion Województwo Mazowieckie, where Warsaw is located, was the last. The Hungarian region HU32 Észak-Alföld had the worst GDP during the last years of the analyzed time period, but alternated its worst place with its neighboring region HU31 Észak-Magyarország. It is obvious that in 2017 not only the CZ01 Praha region but also other regions in the Czechia performed very well in comparison. They took fifth to tenth place. Only the Czech region CZ04 Severozápad placed 16th. Hungarian regions placed the worst, taking five of the last six places.

3.1.1 Cluster Analysis

After obtaining the basic descriptive characteristics, we used the aforesaid data to perform the cluster analysis for the entire analyzed period. The clustering result is best displayed by the dendrogram in Figure 2.

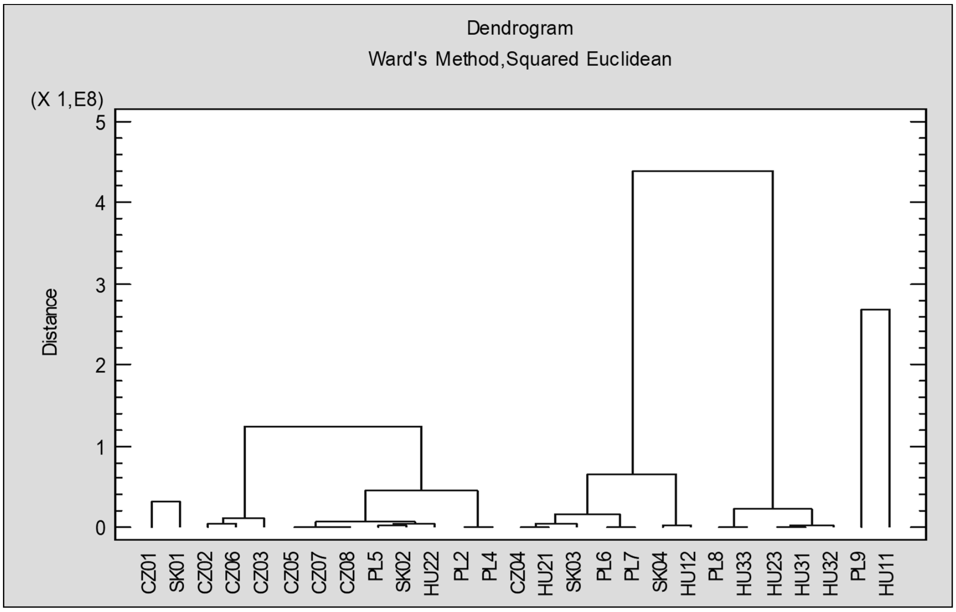

Figure 2 – Cluster Analysis for GDP at Current Market Prices by NUTS 2 Regions (V4)

The results of the cluster analysis are consistent with the conclusions made before. The cluster analysis led to the creation of four homogeneous clusters. When reading the dendrogram from left to right, it is evident that the first cluster consists of CZ01 Praha and SK01 Bratislavský kraj. This cluster combines these two regions with the highest GDP. This only confirms the dominance of capital cities as economic leaders in their countries. The second cluster includes the majority of Czech regions; the third cluster includes the majority of Hungarian regions. The last cluster consists of 2 regions – PL09 Macroregion Województwo Mazowieckie and HU11 Budapest'. This cluster faithfully reflects the real economic power of the regions.

3.2 A Comparison Based on Unemployment Rate

Registered unemployment rate is another macroeconomic indicator, based on which we will compare these regions. In this case, we can compare data for a longer time period because an unemployment rate time series is available for all countries for the years 1999-2018 except the EU28. Data for the V4 countries and their comparison with selected advanced economies are shown in Figure 3.

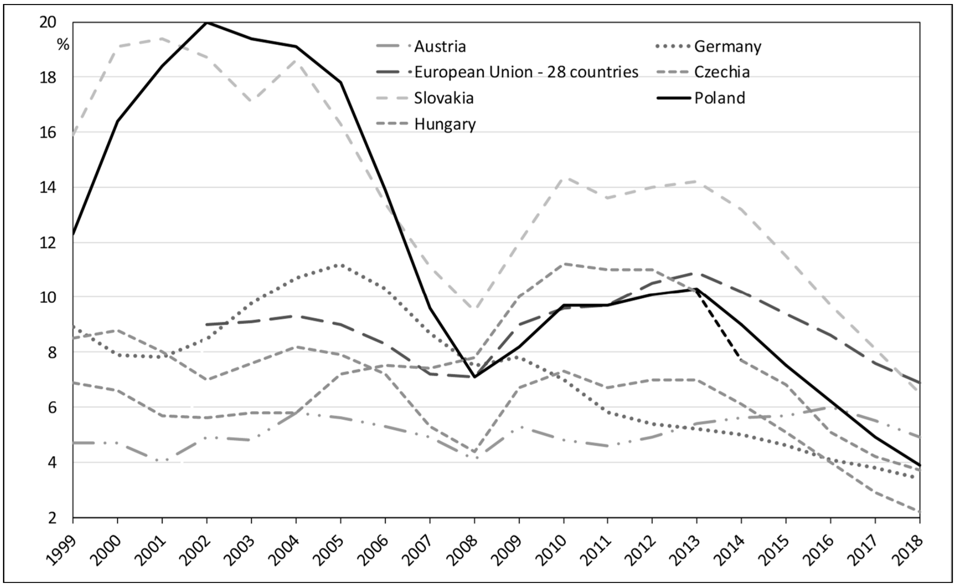

Figure 3 – Unemployment Rate (%) in V4 Countries and Selected Economies

In general, the unemployment rate in all V4 countries went down but varied in the countries due to the persistence of structural factors. These include the size of the tertiary sector, an uneven distribution of skilled labor and a strong focus of many regions on a single industry (see also Table 2). The situation in Slovakia was the worst; its unemployment rate, unlike that in the other countries, was still – despite a significant drop during the last years of the analyzed time period – above the unemployment rate in developed EU Member States. Slovakia as well as Poland also showed the highest employment sensitivity to a worsened economic situation and a significant cyclical increase in unemployment rate in the downturn phase of the economic cycle. The Czechia was again in the best position; unlike in the other three V4 countries, its unemployment rate did not exceed 10% and was below the unemployment rate in advanced economies during the last years of the analyzed time period. The trend in unemployment rate in Poland and Hungary did not differ much after 2008; Hungary's unemployment situation was a little bit better during the last post-crisis years.

The Czech regions did very well in 2018; five of them placed among the top six regions. Slovakia's unemployment rate was high in comparison; the lowest unemployment rate was in SK01 Bratislava, which placed 11th, and the Slovak regions with the highest unemployment rate took the last two places. Hungary showed big differences between regions; some ranked fifth, seventh and eighth, while others were the third and fifth from last. Polish regions also showed big differences, ranking from 10th to 24th place.

Table 2 – Unemployment Rate (Eurostat, 2020c)

	2000	2016	2018
EU – 28 countries	9.0*	8.6	6.9
EU – 15 countries (1995-2004)	8.4	9.1	7.5
Euro area (19 countries)	9.4	10.0	8.2
Germany	7.9	4.1	3.4
Austria	4.7	6.0	4.9
Czechia	8.8	4.0	2.2
Slovakia	19.1	9.7	6.5
Hungary	6.6	5.1	3.7
Poland	16.4	6.2	3.9

Notes: Data 9.0 * is from 2001, data for 2000 are not available.

3.2.1 Cluster Analysis

The situation described in Figure 4 is far from as clear-cut as it was in the case of GDP. From the graphical display, we would expect the cluster analysis to cluster regions with high unemployment. Again, we set the clustering criteria to create four separate clusters. Let's see what the dendrogram for the given data looks like for the whole analyzed period.

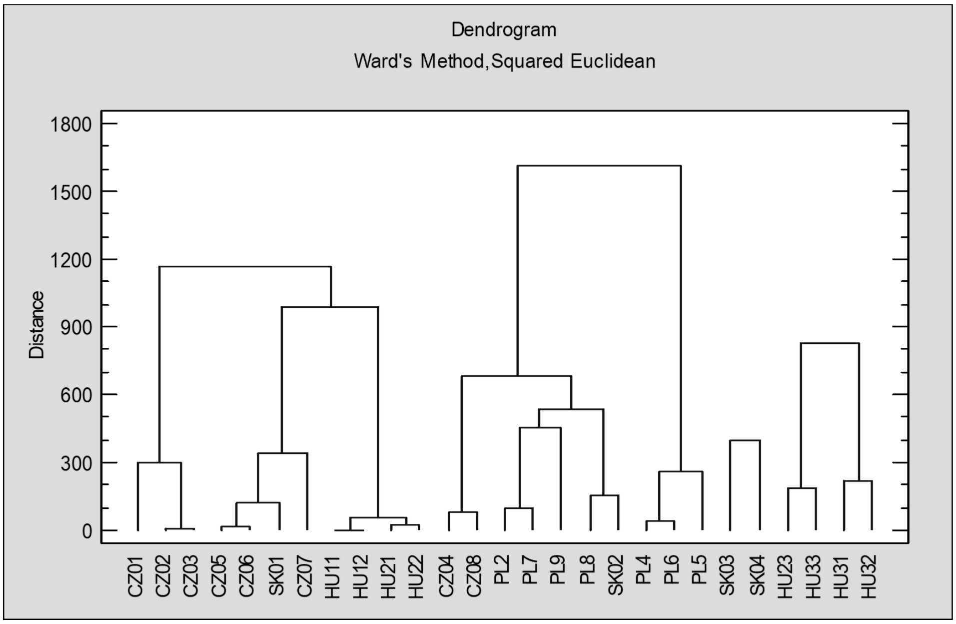

Figure 4 – Cluster Analysis for Unemployment Rates by NUTS 2 Regions (%)

The Czech regions did very well as compared to other regions. Most of them are in the first cluster. Polish regions prevail in the second cluster. The third cluster contains two Slovak regions that – in previous comparisons – did not do well. This was also confirmed by the fact that they form a separate cluster. The fourth cluster consists exclusively of Hungarian regions where the unemployment rate is rather higher.

3.3 A Comparison by Disposable Income of Private Households

Figure 5 shows the trend in disposable household income in individual countries; disposable household income for Poland was available only for the years 2014-2016. Again, we added Austria and Germany to the V4 countries.

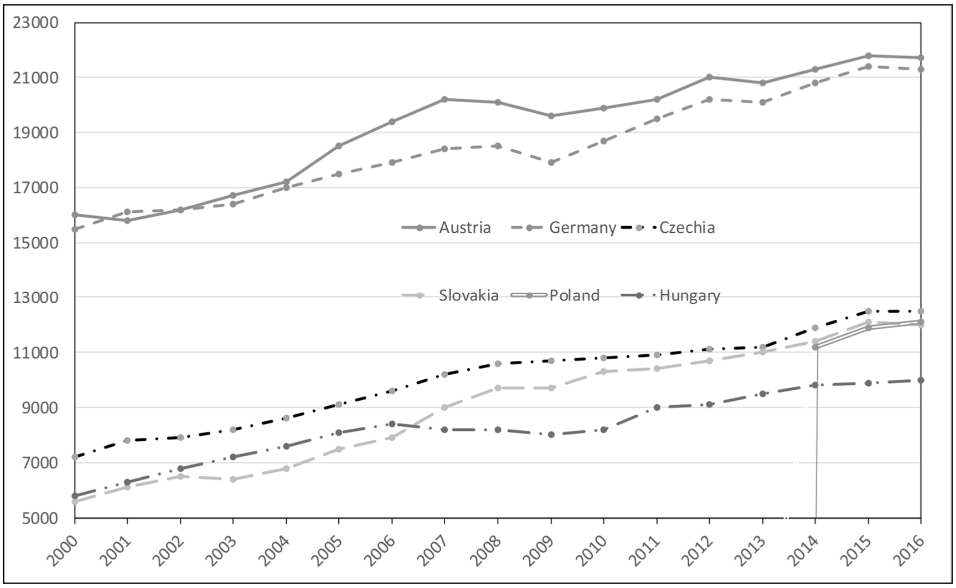

Figure 5 – Disposable Household Income – V4 Countries

The situation in terms of disposable income is similar to that of GDP; there is still a big difference between income in the most developed EU countries and income in the V4 countries. This is not surprising since income represents a relatively stable percentage of GDP. Nevertheless, we can still see certain differences as compared to GDP. At first glance, it is clear that the V4 countries (with the exception of Hungary) are more alike in terms of disposable income than in terms of GDP. It is because income represents a relatively low percentage of GDP in the Czechia, which means a relatively low participation of Czech households in generated wealth. The higher growth rate of disposable income in Slovakia and Poland enabled these countries to get significantly closer to the Czechia in spite of a higher GDP growth rate in the Czechia during the post-crisis period (Figure 5). Nevertheless, disposable household income was the highest in the Czechia during the entire analyzed period. There was not much difference between Slovakia and Poland; disposable household income in Hungary was significantly lower.

These conclusions are also confirmed by the ratio of disposable income in the V4 countries and Germany and Austria (data for the entire EU were not available). Here, too, we can see income convergence, which, however, is slow and insufficient. With the exception of the Czech Republic, income ratios are similar or only slightly lower than in the case of GDP. In the Czechia, this ratio is significantly lower and indicates the above-mentioned low participation of households in growing wealth and room for income growth in the longer term.

Table 3 – Ratio of the V4 Countries to Other Countries

	2000		2016	
	Germany	Austria	Germany	Austria
Czechia	0.46	0.45	0.59	0.58
Slovakia	0.36	0.35	0.56	0.55
Hungary	0.37	0.36	0.47	0.46
Poland	n/a	n/a	0.57	0.56

Notes: Let's look at the results of the cluster analysis.

3.3.1 Cluster Analysis

We applied the principle of cluster analysis with the same parameters, as in the previous cases, to the data for the entire analyzed period. We obtained four clusters and the results were as expected.

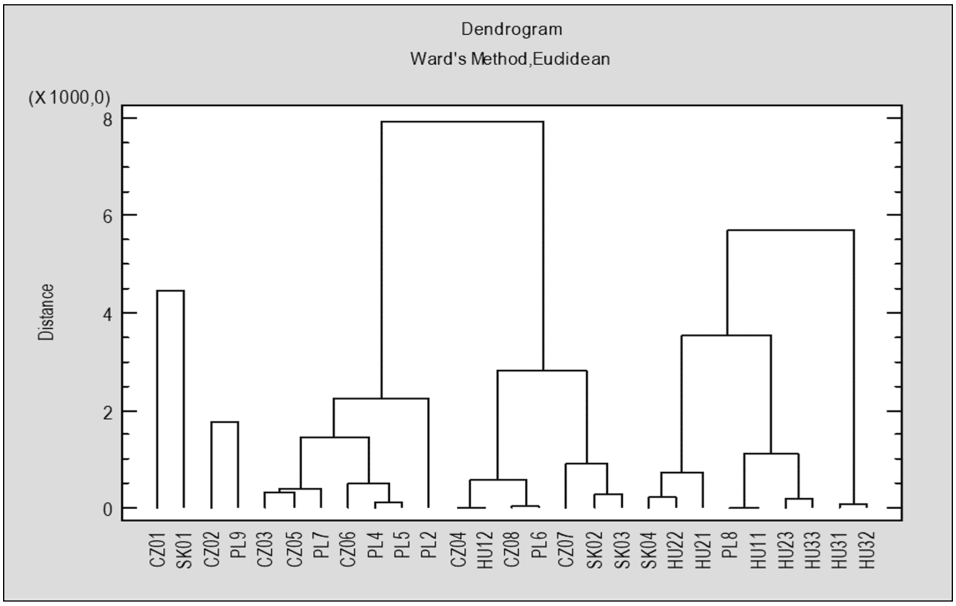

Figure 6 – Cluster Analysis for Disposable Household Income – V4 Countries

Consistent with the previous results, the two strongest regions are included in one cluster. The second cluster consists of the next two strongest regions (i.e. the third and fourth region). The third cluster consists of a large number of regions within similar disposable household income. The fourth cluster mainly represents Hungarian regions, which was expected.

4 DISCUSSION

The goal of the article was to compare a degree of convergence of V4 countries at national and NUTS 2 level. We first made this comparison using basic statistical characteristics and then verified our conclusions based on the cluster analysis. We grouped the regions into four clusters and examined the representation of individual regions in these clusters.

Although the V4 countries form a relatively homogeneous unit, their starting positions before the convergence process began were not entirely identical and these differences persist to some extent. In terms of monitored indicators, the Czechia maintains its best position in the long run, while Hungary performed relatively worst in the convergence process. This may reflect, among other things, the effectiveness of economic policies in individual countries and, in the first phase of transformation, the ability to attract foreign investors through investment incentives. On the other hand, economic development in the period of transformation also has a number of common features. In particular, it appears that the pace of convergence has slowed significantly in recent years and that it will take a very long time or even unrealistic to reach the economic level of the EU's most developed countries. One of the reasons for the slowing convergence may be the phenomenon of the so-called "middle-income trap", when V4 countries have focused too much on the comparative advantage of cheap and educated labor force as the main engine of growth (Eichengreen, Park and Shin, 2013; Ehl, 2016). To re-accelerate the convergence process, it would be necessary to improve overall efficiency and focus on higher value-added production.

Our analysis has shown that countries also have some common features in regional development. Based on all used indicators, we have shown that the regions with capital cities have a completely privileged position and that the other regions lag far behind economically. Inclusion in individual clusters was largely determined by the economic situation in each region. The same regions usually appeared in individual clusters, regardless of whether they were clustered by GDP, unemployment rate or disposable household income. The situation remains stable over time and the regions stay in the same clusters over time.

These results point to persistent disparities between regions and suggest the need for more effective cohesion policy measures to increase the economic performance of lagging regions. The higher growth potential and faster convergence of capital cities can be explained by several factors (Kuttor, 2009).

These are regions with a highly-developed infrastructure, where the majority of economically important companies is based. Thanks to the concentration of universities, these regions have a high percentage of the skilled workforce needed to achieve higher labor productivity and a high-value-added services sector that significantly contributes to the economic output. In this regard, our results have confirmed that the cohesion policy in the regions of the V4 countries should promote innovations and investments into less developed and predominantly agricultural regions, complete the necessary backbone infrastructure and develop a high-quality regional education (European Commission, 2017), which further recommends focusing on a carefully selected specialization with a high-added-value and innovative potential in selected regions.

In this context, it is worth noting that the effectiveness of cohesion policy at EU level cannot lie solely in the effective redistribution of money between countries, resp. relevant regions, but also requires well-prepared programs and good management of individual projects at the local level (see also Wostner, 2008). At regional level, the implementation of high value-added programs may be hampered by institutional factors and a lack of capacity to make the necessary infrastructure or human capital investments. Only the efficient use of allocated funds can help to transform strongly agricultural regions or regions relying on heavy industry into dynamically developing areas.

Our analysis also showed that differences in regional performance are also accompanied by significant differences in employment rates and, consequently, disposable income. Traditionally, agricultural regions and then especially regions with a concentration of mining industry, whose production is already non-promising from today’s point of view and has been gradually subdued, are doing poorly in this area (see, for example, the Central Slovakia region). As high unemployment and low income levels are accompanied by social problems and low education, it is necessary to ensure wider inclusion of the population in the work process and to maintain a sufficient supply of work in order to support the regions. This is again related to the emphasis on effective retraining programs and the growth of education.

It would certainly be interesting to include other macroeconomic indicators in our comparison. However, their availability at NUTS 2 level is relatively limited; even the website of Eurostat and national statistical offices lack a lot of indicators broken down by region. However, the authors of this article will continue with their work and will compare the V4 regions with some developed regions in Europe in their future research.

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AUTHOR CONTRIBUTIONS

Conceptualization, P.R., L.M. and P.D.; Methodology, P.R.; Validation, P.R.; Formal analysis, P.D., L.M. Resources, L.N.; Original draft preparation, P.D., L.N.; Review and editing, P.D.; Visualization, L.N.; Supervision, P.D.; Funding acquisition, P.D.

CONFLICTS OF INTEREST

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Standardisation of the Social Responsibility System as a Tool for Business Sustainability

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ABSTRACT

Purpose: The purpose of the research is to design an innovative model for implementing the integrated corporate social responsibility management system based on the progressive, internationally recognised ISO standards.

Methodology/Approach: This paper analyses the development, current state and trends in implementing the corporate social responsibility system, emphasising the applied approaches and models in the context of possibilities and barriers to their implementation and acceptance in the global markets.

Findings: New market conditions in the global markets within sustainable development require the certification of quality management systems. From this point of view, the integration of management systems is vital, and it brings synergetic effects. Developing the future concept for corporate social responsibility management and sustainability is inevitable.

Research Limitation/Implication: In the meantime, there is no ISO standard as the model for management and the system of social responsibility in the integrated system. The issue is still poorly formalised, developed and appreciated in social practice. The newly revised ISO standards with a 10-element HLS structure and their development and constant addition provide space for the innovative modelling of the social responsibility system in integration with the management of other aspects of the organisation.

Originality/Value of paper: The paper is original due to its focus on the implementation of the social responsibility system in accordance with the latest and newly revised ISO standards in the integrated system form.

Category: Research paper

Keywords: sustainability; social responsibility; management system; integration; ISO standardisation

1 INTRODUCTION

Nowadays, every organisation's priority is maintaining prosperity, performance, competitiveness, and the satisfaction of customers and all stakeholders who operate in its vicinity but also in a globalised environment. On a global scale, the term "socially responsible company" resp. the business has been widely used for several decades and is also highly topical in Slovakia today. It is an essential part of the strategic planning of any organisation, respectively subject. The socially responsible business consists of three basic areas of social, economic and environmental safety (Cingula, Filipović and Primorac, 2009). The standard International Organization for Standardization (ISO) 26000:2011 Guidelines on Social Responsibility is currently used in European legislation. In this sense, corporate social responsibility is defined as the organisation's responsibility for the impacts of decisions and activities on the society and environment, as well as transparent and ethical behaviour that contributes to sustainable development, including health and well-being, taking into account stakeholder's expectations (Castka and Balzarova, 2008). The legislation and international standards of conduct are integrated throughout the organisation and applied in the relations.

The application of corporate social responsibility should be part of the development plan of any organisation whose interest is to increase the level of satisfaction concerning customers and stakeholders (Leonard and McAdam, 2003). The organisation must set the priorities, considering the resources available to achieve the desired results and the needs of other stakeholders. It must consider the results that want to be achieved, but it is also necessary to identify the critical factors that may be a barrier to development (Bocean et al., 2014). The goal of social responsibility is to respect not just social but also environmental and economic sustainability so that the goals of the local and global community are met (Daneshjo and Majerník, 2020). Social responsibility is based on the original idea of volunteering and charity, so organisations aware of the image create a thorough strategy of responsible behaviour towards society and the environment (Balcet, Bernstein and Cashore, 2013).

The voluntariness and diversity of approaches that formulate the corporate social responsibility and sustainability strategies can be formulated, especially in relation to their acceptance from a global perspective, by implementing ISO standards in the organisation's integrated management system (Bussard et al., 2005; Holme and Watts, 2000).

Since 2005, the ISO has started to prepare a new international standard, the purpose of which is to provide general guidance – a framework for implementing corporate social responsibility in a company (Michalczuk and Konarzewska, 2020). The Swedish Standards Institute and the Brazilian Association for Technical Standards were commissioned to develop the standard. These institutions aimed to unify the Working Groups on Social Responsibility. Experts from 54 countries of the world were involved in the project's solution, while an equal representation of women and men was ensured, i.e. diversity of individual opinions is ensured. The added value of the ISO 26000:2011 standard Guidelines on Social Responsibility is the recommendation for companies in relation to Slovak standards (e.g. ISO 9001, ISO 14001, OHSAS 18001 (currently ISO 45001), as well as the Universal Declaration of Human Rights). However, it is not a substitute for these existing national or international recommendations and standards. At present, the topic of socially responsible business is very topical. However, it is less used in practice, but the topicality of this topic is one of the reasons why attention is paid to the issue of socially responsible business (Commission of the European Communities, 2002). Many definitions of a socially responsible company require the company to transfer its social responsibility also in relation to employees, customers, suppliers, local communities, as well as the environment, etc. (Escobar-Sierra and Bedoya-Villa, 2018). The basis of corporate social responsibility is mainly investing in activities that go beyond the legal obligation, and in some cases, the company's management is not willing to engage in the activities that are part of corporate social responsibility (Malindžáková, Majerník and Daneshjo, 2020). The ISO 26000:2011 standard is voluntary for companies and is intended to help companies become aware of their socially responsible business and want to increase their competitiveness (ISO 45001:2018). This standard is not suitable for certification purposes; no standardised requirements exist.

In order to correctly understand the term "the socially responsible company", it is inevitable to clarify the conceptual apparatus. According to Section 5 of the Commercial Code (COM, 2002), the term enterprise is defined as a set of tangible as well as personal and intangible components of the business. The company includes things, rights and other property values that belong to the entrepreneur and are used for the company's operation or, due to their nature, are intended to serve this purpose (Majerník and Boďová, 2013).

Social responsibility is a manifestation of how businesses can influence the interests of other groups in their environment through their activities (SA 8000:2014). Corporate Social Responsibility (CSR) is a continuous commitment of the company to behave ethically, to contribute to the sustainable economic development of the company, and at the same time to improve the quality of employee's life, their families, as well as the local community and society as a whole (STN ISO 9001:2015). According to (Majerník and Boďová, 2012), CSR is a modern business concept that takes into account not only the economic interests of the business but also the social and ethical issues. Dyckhoff, Lackes and Reese (2004) define CSR as a concept by which companies integrate social and environmental issues into business activities and stakeholder relations on a voluntary basis. Social responsibility is a voluntary approach that goes beyond legal requirements because companies consider them to be in their long-term interest. It is therefore not an optional complement to the main business activities, but represents the way the business is managed." Business ethics requires an individual or organisation to act strictly according to certain rules of ethics (SA 8000:2014) and helps develop and implement a Code of Business

Ethics which is a set of principles that express the fundamental values of organisational culture (Crowther and Rayman-Bacchus, 2004). The term related to CSR is also "Philanthropy", one of the modern forms of giving, which seeks to solve society's problems by supporting education, innovation and developing people's ability to help themselves (Zadek, Forstater and Naidoo, 2012). Authors Šaling, Ivanová-Šalingová and Maníková (2008) define philanthropy as a charity, as an effort by individuals to alleviate human misery, occasional helping the socially disadvantaged. Another related term is "Sponsorship", defined as a business relationship where supported organisations undertake to promote the donor's name in their activities. Sponsorship is a consideration (Crowther and Rayman-Bacchus, 2004). Finally, "Sustainable development" is a development that enables the needs of the current generation to be met without compromising the ability to meet the needs of future generations (Harlem, 1987; Wood Campus, 2017).

2 METHODOLOGY

The development of the socially responsible company has a long tradition, and in this context, it is essential to emphasise that this is a rapidly developing area of business (Staniskiene, Stankeviciute and Daunoriene, 2019). In connection with the history of the establishment of a socially responsible company, it is necessary to answer the question: "In what direction, resp. how to do business well?". It is important to do business in such a way that the widest possible circle of people benefits from the business results process. Swift and Zadek (2002), based on their research in the field of socially responsible enterprise, specified the generational stages of CSR development and divided them into the following stages of concept development (Table 1).

Our research is focused on the development of knowledge in the 4th generation as we formulated it in Table 1.

Table 1 – Generational Development of Socially Responsible Business

Development of generations	**Tools and methods**
0. Generation – compliance with legislative regulations	Compliance with laws regarding taxes, health and safety at work, employees' rights, consumer rights, environmental standards
1. Generation – low level of a socially responsible company	Philanthropic activities, short-term risk management, compliance with industry standards beyond legal standards
2. Generation – a strategic socially responsible company	Product and process innovation, new management methods, long-term sustainability
3. Generation – a high degree of socially responsible business	Multi-stakeholder consideration, advocacy and promotion of the CSR, efforts to create a CSR-oriented public policy
4. Generation – integration and standardisation	ISO standardisation. Integrated management systems

Compliance with laws and regulations is a fundamental duty of every business, although this is not part of the principles of a socially responsible business (Majerník et al., 2017; Šalmon, 2003). An overview of key definitions of selected authors is prepared from available sources and an analysis of development trends in the CSR field (Table 2).

Table 2 – Definitions of Socially Responsible Company according to selected authors (Ferencz et al., 2017)

Autor	**Year**	**Definition**
Banard	1938	"... executives must analyse the economic, legal, moral, social and physical aspects of the environment ..."
Simon	1945	"... organisations must be accountable to the values of the community ..."
Drucker	1954	"... management must consider the impact of each business strategy on the company ..."
Selnick	1957	"...a permanent company contributes to the stability of society…"
Friedman	1962, 1970	"...there is only one corporate social responsibility - to use resources for profit-enhancing activities, provided that it complies with competition rules without fraud and deception..."
Andrews	1971	"... the company should have an explicit strategy to support local institutions …"
Fitch	1976	"... companies will achieve social responsibility if they try to identify and solve those social problems that directly affect them ..."
Carroll	1979	"... the business should include the economic, legal, ethical and other voluntary expectations that the company presents to the company at that time ..."
Jones	1980	"... companies have liabilities to several groups that make up a company, not just to shareholders. These obligations go beyond the law and other treaties ..."
Freeman	1984	"... businesses must meet the interests of the various stakeholders ..."
Drucker	1984	"... businesses should turn social problems into an economic opportunity that will bring profit, production capacity, jobs and thus wealth …"
Epstein	1987	"... the consequences of the conduct and conduct of undertakings must be assessed in the light of internal and external stakeholders. Attention is paid to the results of corporate activities ..."
Angelidis a Ibrahim Balabanis	1993	"... the aim of socially responsible activities is to satisfy social needs ..."
Philips a Lyall	1998	"In modern commercial areas, companies and their managers are subject to well-publicised pressure to increase their participation in the well-being of society."
Európska únia Zelená kniha	2001 2002	"The CSR is a concept in which companies integrate social and environmental interests into their activities and interactions with stakeholders."

Autor	Year	Definition
Business Leaders Forum (BLF)	2004	“The CSR is a business concept in which companies voluntarily choose to implement in their business strategies and activities decisions that contribute to improving the state of the business and the cleanliness of the environment, while respecting the interests of all parties involved.”
Nadácia Pontis	2005	“Under the CSR, we understand the continuous commitment of companies to create and adhere to ethical standards, to contribute to improving the economic condition of the company and the environment, to work to improve the quality of life of employees and their families, and to support the development of the community in which they operate.”
ISO 26000	2009	“The CSR is a corporate responsibility for the consequences of its decisions and activities on society and the environment and ethical behavior, which is in line with the sustainable development and prosperity of society, takes into account stakeholder expectations, is in line with international standards of conduct and is integrated into throughout the company.”
Summary of views	2011	The CSR is: “a management system according to which companies integrate economic, social and environmental issues into their business activities - activities and relations with stakeholders, on a voluntary basis in accordance with the requirements of the STN ISO 26000: 2011 standard.”
Our prediction	2021 and further yers	Global standardisation of systems and processes of social responsibility for development sustainability.

Our defined phrase socially responsible company as a CSR management system, according to which companies integrate economic, social and environmental aspects into their own business activities and relationships with stakeholders on a voluntary basis in terms of requirements not only STN ISO 26000:2011 but also other standards. The definitions of the CSR can capture CSR related principles, namely volunteering, initiative beyond what is required by legislation, improving the quality of life, sustainable development and communication with stakeholders (Čaník, 2006).

The subject is the general understanding of the principles of the CSR as well as their application in companies in order to contribute to the sustainable development, health and prosperity of society. The specified principles of the CSR can be applied to all types of enterprises, the size of the enterprise is not specified, nor the location. The principles of the CSR can be applied to governmental and non-governmental, for-profit and non-profit organisations. In the normal course of business, it is appropriate to integrate and implement the principles of the CSR into the various components (departments) of the company (Palucha, 2012). Standard STN ISO 26000:2011 Figure 1 covers 7 basic topics, namely:

1. Organisation a management.
2. Human rights.
3. Working conditions.
4. Environment.

5. Correct business.
6. Consumer care.
7. Involvement and development of local communities.

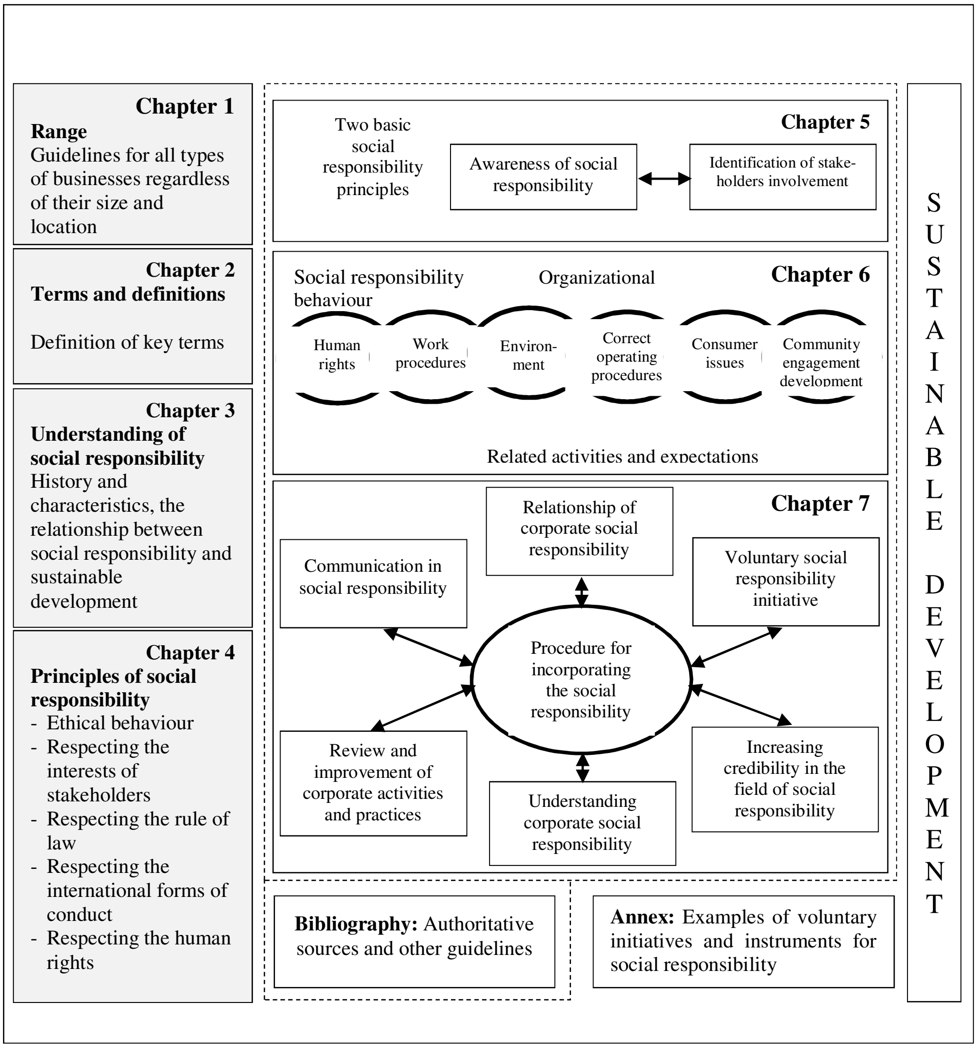

Figure 1 – Basic Principles of Socially Responsible Business

3 RESULTS AND DISCUSSION

In order to increase the competitiveness and sustainability of the company in the market, it is important to identify the indicators, aspects, and possible activities that are preferred by the company with the result of a socially responsible company. The management system keeps the company at the required level, but it is necessary to consider the balance of economic, environmental, social, and institutional sustainable development. These areas are presented by the relevant ISO standards in Figure 2 and the CSR integrated management system concept in Figure 3.

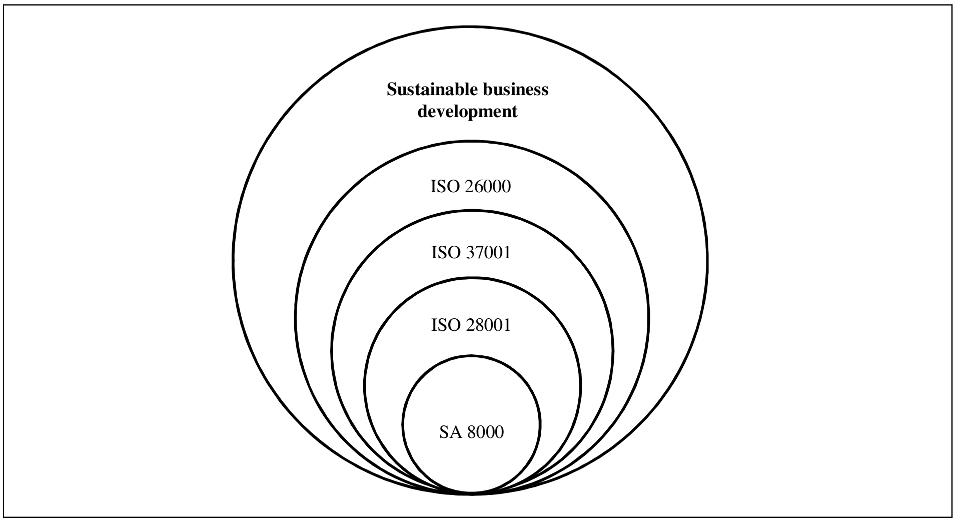

Figure 2 – Key Areas of the CSR Integrated in Accordance with the Requirements of the Relevant ISO Standards (own processing)

The structure of the concept model for integrated management of social responsibility and development sustainability of the organisation in the field of economic, social, and environmental. Figure 3 is made up of the latest revised ISO standards for integration purposes (10-element HLS structure) with the addition of new standards that are not intended for the purposes of certification of the built system. These only provide guidance and require "certification" or their verification (ISO 90001, ISO 14001, ISO 45001, ISO 27001 and SA 8000).

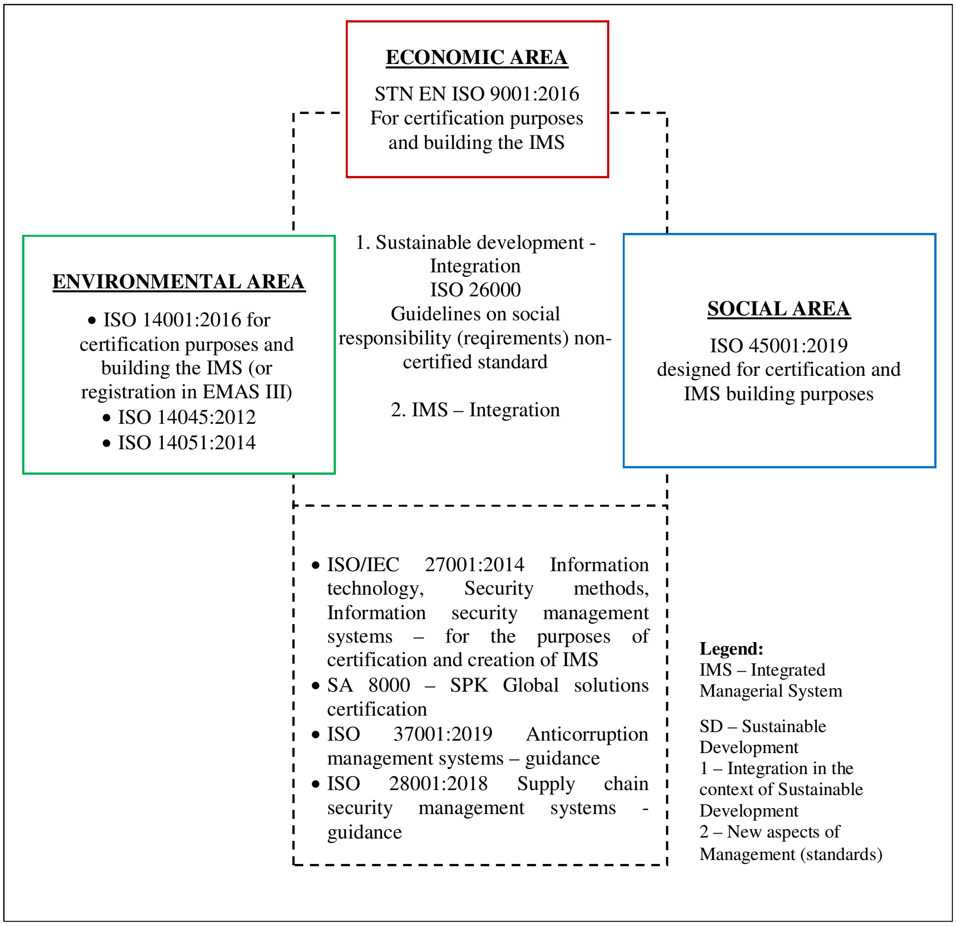

Figure 3 – The Concept of The Model of Integrated Management of Social Responsibility and Development Sustainability of the Organization (own processing)

The functional system of integrated management is focused on continuous improvement of the following areas:

- Environmental, specified by the Environmental Management System (EMS) in accordance with the requirements of the standard ISO 14001:2015 Environmental Management Systems.

  Requirements with instructions for use, as relevant legislation, or the EU Regulation (EC) No. 1221/2009 of the European Parliament – EMAS III and in Slovakia by the Act of the National Council of the Slovak Republic No. 351/2012 Collection of laws on environmental verification and registration of organisations in the European Union scheme for environmental management and audit and on the amendment of specific laws.

ISO 1405:2012 Environmental management. Environmental performance assessment of product systems. Principles, requirements and guidelines (Environmental management. Eco-efficiency assessment of product system. Principles, requirements and guidelines).

ISO 14051:2011 Environmental management. Material flow cost accounting. General framework.

- Economic, specified by quality management system (QMS) by the requirements of the standard ISO 9001:2015 Quality management systems. The requirements, as well as other relevant standards from this family of standards.
- Social, specified by the Occupational Health and Safety Management System (HSMS) following the requirements of the ISO 45001:2018 standard Occupational Health and Safety Management Systems. Guidance requirements for use as well as relevant legislation.
- Other areas focused on CSR are specified, e.g. in ISO 26000:2010 Guidelines on Social Responsibility, ISO/IEC 27001:2014 Information Technology. Security methods. Information security management systems. Requirements as well as relevant legislation.
- ISO 37001:2019 – Specifies requirements and provides guidelines for the anti-corruption management system’s design, implementation, maintenance, review, and improvement. The system can be implemented independently or in the integrated management system of any organisation, regardless of the type, size and nature of the activity, whether in the public, private or non-profit sector.

ISO 28001:2021 – Supply Chain Security Management Systems. This standard specifies requirements and provides guidance for organisations in international supply and logistics chains. It specifies rules for a secure supply chain, including people, infrastructure, transport, resources, etc. In essence, it is a mix of ISO 9001 and ISO 27001 standards supplemented by specific requirements for the comprehensive quality of supply chains.

A synergistic effect in process management can arise from their integration into one model and standard, the purpose of which will be the implementation and verification of the management system of socially responsible and sustainable business. This created standard should eliminate differences in the cultural, social, environmental, economic and legislative conditions. The management interconnection of individual aspects includes the standard ISO 26000, which is focused on the operationalisation of the CSR (i.e. takes into account the steps, processes oriented from theory to empirical facts), identification and involvement of stakeholders, increasing the credibility of reports, and also evaluation of the company’s performance and development sustainability.

The implementation of an integrated social responsibility management system according to international standards can extend both social and corporate benefits in the form of:

- ensuring integrated globally acceptable risk management (economic, social, environmental, security) and their prevention;
- increasing profits in connection with growing environmental and/or environmental awareness and changing consumer behaviour;
- reducing costs in connection with more efficient use of resources, saving materials and energy, recycling, circular economy;
- strengthening the legitimacy of companies in relation to stakeholders;
- intensification of innovation processes and increasing competitiveness in a globalised environment;
- cooperation in building trust and brand producers and more active human resources management;
- increased attractiveness for investors and guarantees of comprehensive quality and sustainability in the market.

The proposed management model may also remove some of the remaining barriers to the current application of social responsibility in practice, such as:

- challenging initial investments, finances, staff, consulting and communication;
- limiting the need for innovation in all areas of the company's activities and management, from product design to external communication;
- the need for cooperation of all three sectors of society (public, business, third);
- conflict of priorities, with unclear standards of social responsibility management.

There is insufficient support from the public administration institutions, a low level of the non-governmental sector, and limited opportunities for cooperation due to a lack of partners.

4 CONCLUSION

The main goal of socially responsible and sustainable business is good and fair cooperation between stakeholders. Support in improving relationships consists in maintaining and developing them (Auld, Bernstein and Cashore, 2008). Organisations need to be aware of the benefits of social responsibility and sustainability goals, but on the other hand, they can hinder innovation. It is essential to integrate the process of social responsibility into the activities of the company. Through innovative corporate social responsibility management, it is possible to contribute to openness, integrity and accountability to increase stakeholders' trust in the company and its activities.

Within the synergy of corporate social responsibility and environmental protection, it is also necessary to consider the optimisation of waste management processes. Through waste recovery and using the best available waste treatment technology, emphasis is placed on increasing corporate social responsibility for the comprehensive quality of production (Rahim, 2014).

In connection with the relationship corporate social responsibility – environmental protection – globalisation brings the introduction of new and more efficient global structures (Hahn, 2012). The role of companies in terms of sustainability will not only be to review but also to adapt the company's strategy in 6 areas:

1. Market coverage.
2. Trading system configuration.
3. Marketing.
4. Business partnership.
5. Environmental protection.
6. Waste management.

For the global development of science and technology with a link to corporate social responsibility, the DELPHI'98 study (Frauenhofer Institute, Germany) was also prepared for 13 areas of innovation by 2025: information and communication, services, management and production, chemistry and materials, health and environment, agriculture and nutrition, environment and nature, energy and raw materials, construction and housing, mobility and transport. The dynamic development of the relevant partial globalisation processes is related to the protection of biodiversity as well as the protection of forest ecosystems. From an environmental point of view, it is important to mitigate the effects of climate change, and it is also necessary to pay attention to the carbon footprint.

The introduction of an Integrated Management System (IMS) for socially responsible and sustainable business following the requirements of ISO 26000 and the application of other ISO 9001, ISO 14001 and ISO 45001 contributes to sustainable economic growth and competitiveness of the company. On the other hand, the gradual reduction and compensation of the negative impacts of its activities, products and services on the environment and health. This strategy of socially responsible business based on the principle of sustainable development, which ensures the current needs in a balanced way, is also a double profit strategy. Reducing the burden on the environment through the so-called "Cleaner technologies" will improve the quality of the environment and production and simultaneously increase the business entity's competitiveness, balancing the economic, social and environmental dimensions of business (Herciu, 2016).

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Conceptualisation, M.M. and J.Š..; Methodology, M.M..; software, P.M..; Validation, P.M. and B.B.; Formal analysis, J.Š.; Investigation, J.Š.; Resources, P.M.; Data curation, P.M.; Original draft preparation, M.M. and B.B.; Review and editing, P.M.; Visualization, P.M.; Supervision, M.M.; Project administration, M.M. and J.Š.; Funding acquisition, M.M. and J.Š.

CONFLICTS OF INTEREST

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Analysis and Possibilities of Innovation of the Business Model Called Central Regulation Using Blockchain Technology

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ABSTRACT

Purpose: This paper clearly describes the possibilities of digitising a purchasing group's processes using blockchain technology. The main focus lies on its core business, financial service called central regulation and other services.

Methodology/Approach: After reviewing the literature, the most prominent blockchain projects in recent years in large companies were depicted to identify successful adoptions. The processes of purchasing group were described with the extension of innovative blockchain technology. A summary of potential advantages is presented in a table.

Findings: The conclusions could potentially be of a benefit to the management of purchasing groups as evidence suggests an increase in transparency in the whole process of the supply chain and, at the same time, bring effectiveness in payment processing. Combining permissioned and permissionless blockchain could be a viable solution for a purchasing group which uses a central payment system.

Research Limitation/Implication: The main limitation is the impossibility of testing the usage of blockchain technology in real-life conditions on a full scale. However, a sample of processes could be modelled further to test and develop the improvements and measure various parameters.

Originality/Value of paper: This approach is the first of its kind as there is no literature or publication on the usage of blockchain technology in the central regulation system. This paper can help with the decision-making process at the management level.

Category: Conceptual paper

Keywords: blockchain; central regulation; del credere provision; supply chain; digitalisation

1 INTRODUCTION

In a rapidly changing digital environment, small and medium-sized enterprises (SMEs) often have problems fighting big competitors. To stay successful in the market, they can join buying groups or purchasing associations whose primary role is to empower SMEs. In Western Europe, these associations often use a business model called in German "Zentralregulierung" (central regulation or central payment system), which has long history mainly in Germany and is based on payment settlement between contracted suppliers and buyers. The company which offers this kind of financial service guarantees payments to suppliers for all buyers, and for this guarantee, the Del Credere provision is paid by suppliers. As technological development advances, the business model must be adapted flexibly to this situation. Recent years show that blockchain technology is being used more frequently, and it has the potential to disrupt various sectors.

After describing the conceptual framework, possibilities of innovation of the central payment system using blockchain technology are presented as well as limitations and challenges which could pose a risk to the real-life application of this model. Finally, this paper offers an overview of how the whole procedure will change in both areas – financial services of central payment and blockchain technology used on all processes behind central payment – supply chain of goods and services. This is supposed to cut costs in payments infrastructure and speed up all transactions between users. Additionally, traceability of product provenance will push the whole supply chain to a completely next level.

2 LITERATURE REVIEW

The blockchain is a distributed ledger technology (DLT) in the form of a distributed transactional database secured by cryptography and governed by a consensus mechanism. A blockchain is essentially a record of digital events (Beck et al., 2017). There are already many fields where blockchain is being used, and many advantages will contribute to global economic growth. For example, according to PwC analyst report from October 2020, the global gross domestic product can increase by 1.76 trillion USD in the next ten years using blockchain technologies in various businesses (PwC, 2020).

The world is facing rapid development in the digital sphere within Industry 4.0, or the Internet of Things (IoT), where machines and things are networked via cyber-physical processes (Zimmermann, 2020). This phenomenon is spreading fast throughout the world, and according to the Ericsson mobility report published in 2018, cellular IoT connections grow annually by 30%. They estimate that in 2023, over 31.4 billion devices will be connected via IoT (Ericcson Mobility Report, 2021). The fourth industrial revolution refers to automation, digitisation of processes and increased production efficiency. Blockchain technology is often seen as a driver of this change, focusing on artificial intelligence, cyber-physical systems, machine learning and IoT (Aoun et al., 2021).

Unique properties of blockchain offer unprecedented possibilities in corporate business. The necessity to rethink the traditional supply chain management arises from problems such as difficult logistics tracing, information and documentation flow or information asymmetry. The characteristics of blockchain technology bring entirely new possibilities, advantages and value-added potential for handling business processes, describing the status of products, exchanging information with stakeholders and new business models. Blockchain technology can transform existing business processes and significantly increase efficiency, reliability and security (Choo et al., 2020). Therefore, blockchain technology will increase massively in the coming years. Its use can generate certain economic benefits for companies and customers.

3 METHODOLOGY

In this paper, we focus on collecting and selecting relevant literature and appropriate information sources from previous studies, scientific articles and papers, which are presented in the literature review and description of frameworks. In part devoted to blockchain technology, we provide insights into various successful use cases in various areas such as supply chain and finance. Then, we describe the central regulation system as a business model used by purchasing associations, and we continue by incorporating blockchain into its infrastructure. After selecting the most crucial criteria, we carry out a comparison table to summarize the differences between the old and new innovative central regulation model. Finally, we point out some possible limitations of applied technology and propose further research opportunities.

4 FRAMEWORK OF BLOCKCHAIN SYSTEM AND ITS APPLICATIONS

Distributed ledger technology is understood as a system with multiple participants, which works without a central control authority despite the unknown reliability of these participants. According to (Yu et al., 2018), blockchain is an “append-only decentralised digital ledger based on cryptography”.

Records cannot be modified or erased, and only new data can be added to the existing one. The peer-to-peer network enables each participating computer that owns a copy of the files to act as a client and a server for other participants in the blockchain network (Schmidgal, 2021). This endless chain of blocks with data enables traceability and the possibility to verify transactions at any time. (Mandolla et al., 2019). Depending on the configuration of blockchain, there are four common types of blockchain – public also known as permissionless blockchains, private blockchains called permissioned blockchains, consortium blockchains or hybrid blockchains (Wegrzyn and Wang, 2021).

The first public one is mainly used in cases of cryptocurrencies, in digital identity projects, electronic voting or fundraising. A public blockchain is 100% decentralised and anybody is allowed to enter the network and interact with it by staying anonymous. However, suppose the company cannot allow sharing all information within the public network. In that case, it decides on a private blockchain, which is primarily used in banking, in the food industry or supply chain management. It is less decentralised than a public blockchain and not everybody can join or interact with this blockchain. Governance is in the hand of some central authority (organisation, government, or group of companies). Transactions are private, and fewer participants are allowed to validate transactions. This results in extremely fast verification of transactions and it requires less energy than a public permissionless blockchain. It is also more flexible and customisable. Another type of permissioned blockchain is consortium blockchain which is managed by a group of companies, not only by a single entity. It is more decentralised than a private one, which leads to more security. The last type of blockchain is a hybrid version of both public and private blockchain. A single authority controls this network, but it also has a public blockchain to validate some transactions. (Wegrzyn and Wang, 2021)

From previous research about blockchain technology, we can summarise the following features as the main characteristics of blockchain technology, which economic benefits can arise from: decentralisation, data management, resilience, cryptography, irreversibility, connectivity, digitisation, synchronicity, safety, non-falsifiability, transparency and traceability. (Dutta et al., 2020)

4.1 Successful Blockchain Applications

Although it is foreseen for SMEs to start exploring possibilities that the blockchain can offer evidence of successful applications is more visible in large companies. Blockchain integration is a cost-sensitive topic in SMEs, and a set of conditions must be met to achieve desired outcomes. Most importantly, it is a network effect, the presence of common goals of participants in the market and a need for trust and transparency among partners.

The most important fields of usage of DLT/ Blockchain are:

1. Optimisation of contractual obligations
2. Automation and optimisation of business processes
3. Work with digital assets
4. Digitalisation/tokenisation of assets
5. Optimisation and automation of data storage
6. Optimisation of supply chain

7. Increase in the effectiveness of transactions
8. Increase in business transparency

As such, blockchain is significantly more flexible with data than existing legacy digital systems as it provides almost real-time settlements of transactions.

4.2 Applications of Blockchain Technology in Corporations

Although some pioneer projects started in 2008, many projects of a more extensive scale were introduced in 2019. In the meantime, providers and consultant companies on blockchain technology emerged with leaders such as Amazon Web Services (AWS), IBM, Infosys and Wipro, followed by others, especially the Big4 consulting companies. (IDC, 2020)

If we look at successful applications of blockchain technologies, we can divide projects into categories: Supply chain, Finance and Documents transparency.

4.2.1 Supply Chain

The most common use of blockchain seems to be in the supply chain – transparent tracking of goods from raw materials to final product sales. When looking at Automotive industry, many corporations have already started pilot projects in this area, such as Tracking production process in Jaguar Land Rover (Ledger Insights, 2021), the PartChain project to trace parts and critical raw materials in BMW Group (2020) or more transparent and secure process of tracking raw material (Volkswagen AG, 2019). In food & beverages industry, the most active are Walmart, Nestle and Carrefour and companies like Anheuser-Busch with its subsidiary Budweiser (Castillo, 2019) and Peroni (Ernst & Young, 2021). TradeLens by IBM with Maersk includes over 100 logistic companies as a part of blockchain for shipments. Members are companies such as ports, sea and land carriers or customs agencies (IBM, 2018).

4.2.2 Finance

A great example of the usage of blockchain on a big scale is Singapore Stock Exchange which enabled trade settlement to be reduced by 60% (Amazon Web Services, 2020). Another evidence can be seen in Munich RE which tested, among other cost-saving effects of blockchain for insurance, specifically, automation in claims payments. Additionally, potential insurance fraud can also be avoided (Munich Re Life US, 2020). Allianz SE is selling flight-delay insurance based on blockchain connected to flight information, meaning that as soon as the information about delay/cancellation is obtained, the claim is initiated and the customer can get reimbursement much sooner (Allianz Travel Insurance, 2022).

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4.2.3 Documents Flow and Transparency

VW Financial Services in 2021 started a blockchain project on E-signature and Digital Contracts bringing digital identity solutions with blockchain-verified e-signature. This solution is currently in use in the UK (Bloomberg, 2021). Big4 companies also advocate for blockchain, as it brings transparency into the documentation flow. For example, it would be much easier in the auditing process to check selected material invoices if they are part of the blockchain. Often, an expression digital asset is used to describe, e.g. invoice converted into a smart contract and integrated into the blockchain. Such digital assets can be relied on by investors, buyers or liquidators in the verification process (Thrill, 2018).

Many of the previously mentioned applications are evidence that buying associations, mostly famous within Germany will be forced in the near future to deal with this new technology in order to stay competitive and stay in the game. More and more industries will slowly start to require such blockchain connections from their suppliers.

5 FRAMEWORK OF CENTRAL REGULATION SYSTEM

The primary aim of improvement is to simplify financial settlements between contracted suppliers and members via purchasing association and ensure punctual payment of all invoices between these two parties. The contracted suppliers rely on safe and fast payments for all goods sold to all members, and for this service, suppliers are willing to pay the “del credere” provision as compensation for secured cash flow (Merriam-Webster.com, 2018). This helps suppliers plan better as the payment is guaranteed even in case of insolvency of a member. On the other side, there are members who pay for all their purchases from contracted suppliers to one central place – the association. For them there are other advantages, for instance, cumulated payments, possible longer payment terms and reduced transaction costs. If an association wants to settle payments via central regulation system, it is necessary to have a contract with a bank which is licensed to provide these services.

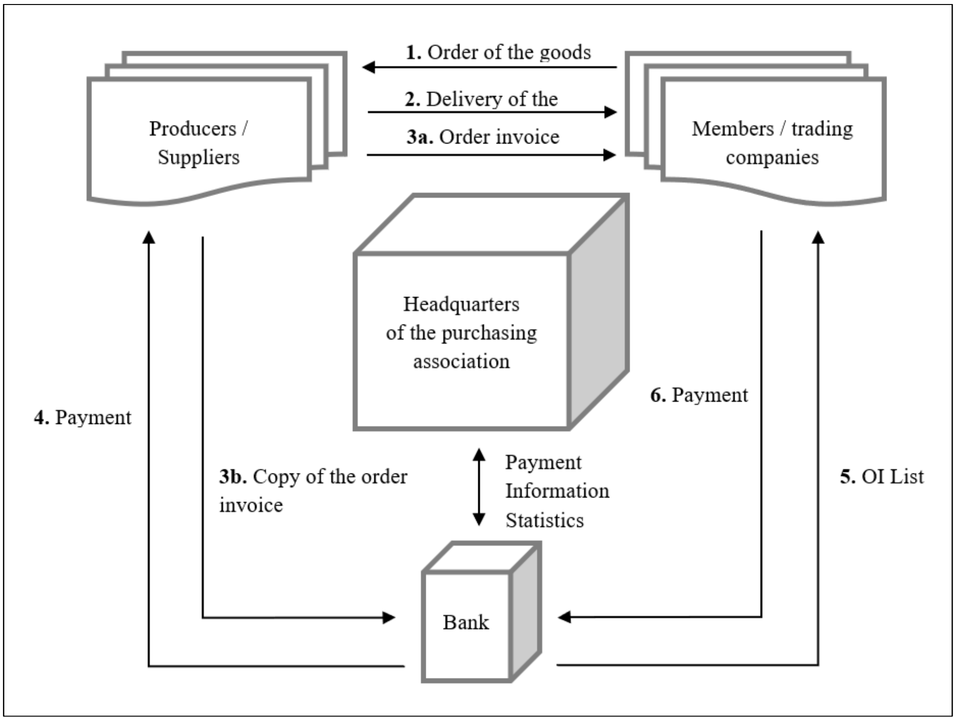

Figure 1 – Process of the Central Regulation System

The whole process of central regulation can be described in the following steps:

1. Trading company/member orders the goods directly from the supplier and receives order confirmation with price and estimated delivery date from the supplier.
2. Goods are delivered from supplier directly to member.

3a. When goods have been received, an invoice will be issued and sent directly from supplier to member (original invoice)

3b. In this step purchasing association steps into this process as the third party. Association (in particular the commissioning bank with bank licence for central payment) gets a copy of the invoice for central regulation from all suppliers.

4. Association pays suppliers for all members within agreed payment terms. The main advantage for the supplier is that association guarantees payments for all member companies. For this service association is charging del credere provision which is being deducted from the total amount stated on the invoice.
5. Open item list (OI List) will be issued for each member company once or twice a month. This OI List contains all cumulated invoices from all suppliers.

6. Money transfer from member to the association is done according to agreed payment terms just once or twice a month. The advantage for members arises from cumulated payments of all invoices in the given period of time instead of paying each of them separately. In total, it can significantly reduce administration costs, working time in the bookkeeping department and transaction costs.

6 ANALYSIS OF INNOVATION POSSIBILITIES OF CENTRAL REGULATION SYSTEM USING BLOCKCHAIN TECHNOLOGY

Since the central regulation system is managed by the association that connects suppliers and trading companies, a private blockchain will be applied because not all information can be public. Every invoice in the central regulation represents goods from the contracted supplier which the trading company then sells to the end customer. Even with electronic data interchange (EDI) solutions which enable digitally access and exchange of data of all transactions and products, it takes a long time and human resources from various departments to obtain complex information about the chosen case. This is ineffective and can be eliminated by implementing blockchain technology in this system.

Since every transaction between supplier, member company and association require gathering information about current price and availability, price negotiations and arrangements or contracts, there are always transaction costs involved in all these business processes. Moreover, opportunistic behaviour of all parties is present and focus on self-interest can lead to breach of contract. With blockchain, it is possible to transform these arrangements and contracts into smart contracts based on an algorithm. Then, action will be triggered automatically without human interaction only when a predefined condition is met. This can simplify the monitoring process which in the old model required much time.

We believe that advantages such as reduced operation time and transaction costs arising from the central regulation model using blockchain can incentivise each participant to behave according to the agreed terms and conditions, which can be saved in blockchain as smart contracts. Furthermore, innovation of this blockchain-based model will bring transparency to all participants and enable to optimise and speed up cooperation between companies by reducing manual work and operational processes.

The new model in Figure 2 is based on the assumption that all suppliers and members will participate on this permissioned blockchain where the association is the entity which decides who gets permission to join the network and interact with other participants.

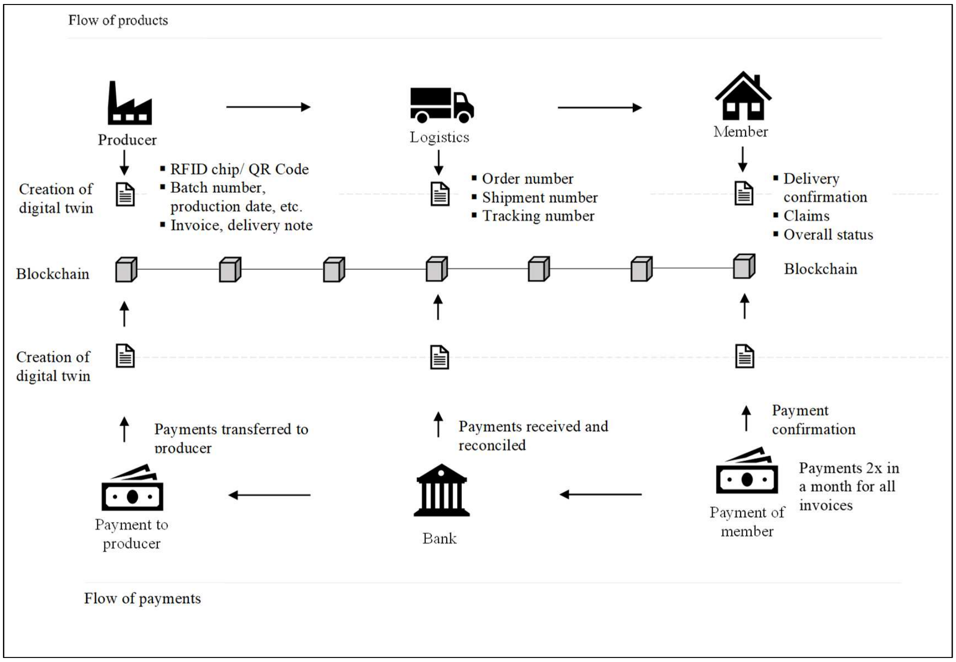

Figure 2 – New Structure of Central Regulation Model Using Blockchain Technology

We see two flows within this model – product flow and payment flow. Some suppliers can be direct competitors and each of them has digital identity within the system. However, they cannot see information about other competitors and vice versa, so they can be sure that their information is private and secured and via smart contract visible only to members who demand the supplier's product.

Every participant is creating digital twin by recording all necessary data about product or payment. Before every block is mined, it has to be validated by all nodes within the blockchain. After this validation new block is added to the chain of blocks with reference to the previous block. Smart contracts are integrated into this structure in order to set up all necessary conditions between participants. All these contracts have predefined conditions, and an automated action will be triggered after validation. For instance, after receiving confirmation from the supplier about goods sent, the system will match this transaction with smart contract, which was already verified by the network and in the following step association will automatically pay the supplier according to the agreed payment terms with deduction of del credere provision for payment guarantee. All these transactions are recorded in an immutable and independent chain of blocks, and these data can be traced at any time. In case of malicious behaviour, the block will be caught because smart contracts react to this by detecting this fraud and the participant could be penalised.

Payments within the central regulation system will be executed automatically without human intervention when previously agreed terms are met. This leads to decreasing costs for the accounting department. Furthermore, payment terms are arranged separately between association and supplier and between association and the member company. Once these payment terms are implemented into smart contracts and verified by the network, nobody has to remember them and monitor them to pay in time because these due dates will be automatically identified.

Reduced physical contact via e-mails or phone may significantly change the whole purchase order management. Since everything can be traced reversely, nobody intends to compromise these certificates, ensuring transparency and security for members and suppliers. When the product is shifted to a logistics company and is sent to the member all information from the logistic company is also recorded in blockchain so that the supplier and member can track the delivery process. After the completed production and transaction cycle, customer satisfaction can be evaluated and recorded on blockchain.

Customer feedback on their products via blockchain enables continuous production process improvement. This feedback can be analysed and used for product development or adjustment. In the payment part, each payment behaviour is recorded and analysed in real-time. This helps to discover whether some companies tend to have financial problems and act very quickly to avoid insolvency cases of member companies.

This system will encourage producers to produce in their best quality, and finally, blockchain technology can improve profitability and performance in the industry. Additionally, authorities like tax and financial offices, auditing or insurance companies will encourage companies to implement blockchain technologies because it will simplify the correspondence and submission of documents and papers required for examination by these authorities. As a result, such a company could get a higher rating because of the transparency and security of all operations.

Furthermore, direct access to all statistics regarding manufacturing processes, logistics and sales can help associations, suppliers and members monitor the whole supply chain and continuously improve all procedures and transactions. Finally, this innovative model affects the whole value chain, which means that producers and associations have to think about the price of their products and services. Therefore, high investment costs on one side and reduced transaction costs will play a crucial role in the new pricing model.

Table 1 – Comparison of Chosen Parameters in the Old and New Innovated Model

Parameter	**Old Central Payment Model**	**New Central Payment Model Using Permissioned Blockchain**
System structure	• centralised system • a single entity or group of entities control the whole system (the group association via the bank) • they have full control over the whole procedure	• decentralised system • participants validate the whole system • smart contracts automatically execute actions when predefined conditions are met
Hardware	• system based on central web server, where all data are stored • proper backups are necessary to avoid data loss in case of a hardware crash • system crash causes loss of time and profit	• there is no single server which can crash and thus stop operational business • if some of the nodes or peer does not work properly, there are still many other nodes which can validate transactions on the network
Safety / Security	• the system can be hacked • the association works just with partners regularly monitored by the bank • payments are conducted via financial institution - bank (high security)	• only transactions validated by all required nodes will be made and recorded in the blockchain • transparent and secure payments • fraudulent behaviour automatically revealed – minimised risk of fraud
Trust issues	• centralised trust-based system • user has to trust the issuer • just the issuer can verify the process and the system • information asymmetry can be misused by issuer • user cannot verify if transactions are handled correctly • more possibilities for fraudulent behaviour	• decentralized / distributed trust-free system • every fraudulent behaviour can be detected, recorded and penalised - resulting in bad rating or end of coop. • additional trust is easily achieved in cooperation between more than two parties
Maturity of the model	• well known on the market for many decades • used mostly in German-speaking countries in the industry	• still in the developing process • new modern technology with some limitations which need to be clarified before implementation
Transparency	• transparency is achieved at some level, but in order to find something out or to make an analysis, it is necessary to gather data from more places within firms	• fewer misunderstandings • defined protocols rule all transactions • operations within smart contracts are transparent as confirmed by participants • retrieve statistics of revenues and sales for all transactions in a few seconds • effective communication with authorities, more accessible and faster auditing

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Parameter	**Old Central Payment Model**	**New Central Payment Model Using Permissioned Blockchain**
Traceability	• possible, but very time-consuming • high costs and long waiting time to get the result (many people involved in this process) • data are isolated and fragmented	• suitable in industries with strict regulations about product provenance • in supply chain traceability is possible via digital twin of the product • possibility of real-time analysis of the status • goods can be tracked at every point of the supply chain
Contracts and Agreements	• arrangements and contracts are closed between partners in standard way • legal department archives these contracts in paper and digital form • monitoring requires manual work to determine whether participants' actions comply with contracts • time-consuming bureaucracy	• smart contracts are created within the network and actions are triggered automatically when predefined criteria are met, human intervention is not necessary • minimised bureaucracy • possibility to integrate multiparty agreements • automated execution of terms and conditions in every stage of supply chain with more participants - everything is tracked and recorded
Supply chain	• transparent only after corresponding between supplier, member and association • tracking of goods possible from shipping company - necessity to connect to the shipper's platform • tracing the product is more complicated and takes more time • human interaction can lead to errors • information asymmetry	• every stage of supply chain is recorded in blockchain • highly transparent • order management more efficient • real-time tracking of goods • enhanced supply chain • error elimination because of automated processes using smart contracts • reduction of physical documents • more consistent information
Payment	• manual work for bookkeeping department • delays in receiving documents can occur which can lead to late payments	• automated transactions using smart contracts - payment within agreed payment terms. • easy monitoring of payment flow

In the use cases mentioned in this paper, we can see evidence that the industry will require more and more possibilities to track product provenance during the product's complete lifecycle. In our innovative central regulation model, we can see the beginning of data blocks by the supplier who produces his products. In order to track products completely which will be demanded in future, we have to think one step further by involving pre-suppliers of raw materials in blockchain. This is, according to many experts, the future of businesses and the sooner the managers of associations realise the importance of this technology, the bigger and better competitive advantage they can achieve compared to competitors because until now there is no evidence in the market that such associations are planning to introduce this technology to their business model.

6.1 Limitations and Challenges

There are of course some limitations regarding this technology which need to be considered in decision-making about blockchain. The world is changing as rapidly as blockchain technology is being developed and there could be other technologies in the future to which blockchain can be vulnerable and not stable, such as supercomputers. Fast and reliable internet connection and enough space to download all data from the blockchain are also demanding components of this system. Furthermore, as the database grows exponentially, one limitation can be a storage space.

Another aspect is initial costs connected to this technology which in case of single SMEs could be nearly impossible to finance independently. On the other side, being a part/member of an association could be optimal for SMEs because of sharing costs between many members. Investment return will be significant before deciding about blockchain implementation.

Blockchain is often criticised for its immutability because recorded transactions cannot be changed. This can lead to the problem that if the information contains errors, this error cannot be corrected or adjusted. Furthermore, the regulatory and legal framework could be of severe other concern within using blockchain-based solutions within international companies since jurisdictions of various companies sitting in other countries can differ from each other.

7 CONCLUSIONS

Since industry will require more monitoring of supply chain, purchasing associations using central regulation model have to think about innovations in order to keep up with globalisation and digitisation. Modern technologies like blockchain are winning more attention and seem to be an appropriate tool to improve supply chain and transactions between supplier, association and member companies. After studying previous research, we proposed innovation of the central regulation model using blockchain technology with a clear objective – to speed up and optimise processes and thus reduce costs.

There is a tremendous interest of many companies in implementing blockchain in various fields and processes within organisations. This interest was even more accelerated by pandemics which triggered the transformation toward new modern technology. Investment costs connected to implementing such blockchain technology are very high when created internally. However, evidence shows that external providers of blockchain-as-a-service are gaining popularity on a global scale. When applied at a purchasing association, SMEs and suppliers participating in blockchain can benefit from shared costs. Blockchain-based solutions offer great conveniences to business organisations and open the door to an entirely new level of financial and supply chain management.

Process excellence and more efficient operations – one motivation to analyse possibilities of adopting this technology. Thanks to the digitisation of all operational processes, faster supply and payment management are expected, and this can lead to a higher volume of sales and payments thanks to automation. Some examples from various industries mentioned in this paper proved that a blockchain is a viable option, simultaneously achieving time effectiveness and transparency to the whole process.

This article is intended to serve as an indicator for managers of such associations to see a potential in implanting blockchain technology which is spreading very quickly. Some of the essential market participants are already using this technology to some extent and it is just a matter of time when the whole industry will switch to such solutions. SMEs as members of bigger associations should rely on these entities to help them survive in the modern digital world. Many predictions show where we are heading and blockchain-based solutions will be used daily in the future in many fields and industries. The primary motivation of this paper was to articulate an upgraded central payment model by blockchain technology based on successful blockchain applications in important international corporations. As complete transition could be discouraging initially, corporations could simultaneously start a trial with the parallel solution – using blockchain and legacy approaches.

Further research should examine specific technological requirements which could be applied in purchasing associations and estimate savings achieved by transitioning to blockchain solutions. Balanced Scorecard methodology as a performance measurement tool for management could be used in order to prepare verification for management whether blockchain technology applied in purchasing association will bring desired results and benefits. Furthermore, publicly traded companies which already applied blockchain could be analysed to prove if and how blockchain application affected stock price in different time periods.

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Conceptualisation, V.G.; Methodology, V.G.; Formal analysis, V.G.; Investigation, V.G.; Original draft preparation, V.G.; Review and editing, M.S.; Visualization, V.G.; Supervision, M.S.

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.

Closed-Loop Quality Management Systems: Are Czech Companies Ready?

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ABSTRACT

Purpose: The paper brings set of original information related to the next quality management systems development with regard to digitalisation and other features of new era. It proposes basic structure of closed-loop quality management systems (CLQMS) as a mixture of internal, external, horizontal and vertical loops.

Methodology/Approach: Comparative literature analysis, standards' analysis, brainstorming, field research, interviews and design review were used.

Findings: Information flows are counted as vital part of all advanced closed-loop quality management systems. Authors established definition of CLQMS. 209 of various requirements related to information exchange were discovered through study of ISO 9001:2015, IATF 16949:2016 and EFQM Model, version 2020. These requirements should create a basic platform for CLQMS establishing and development. Authors performed an empirical field research which. Confirmed that current readiness of Czech production companies for CLQMS implementation is insufficient, despite the automotive sector reaches a higher level of such readiness.

Research Limitation/Implication: The field research was performed in time span accompanied by stern measures caused by COVID-19. The only English language literature resources were considered for a literature review.

Originality/Value of paper: The paper brings original set of information, regarding to definition of the CLQMS, findings from special field research.

Category: Research paper

Keywords: closed-loop quality management; quality 4.0; management system; feedback loop

1 INTRODUCTION

Consistently meeting all stakeholders' requirements (especially oriented to the future) poses a permanent challenge for all types of organizations. Hence quality management systems based on various standards or excellence models will be an important part of overall management systems. Unfortunately, a lot of certified quality management systems, mainly against ISO 9001:2015 requirements are rigid, static and they do not comply with current demands on new era of digitalisation.

Zairi (2018) even argues that total quality management has become redundant. Anyway, meaning of quality management is commonly recognized. But traditional approaches to the quality management and structures of current quality management systems will have to be transformed in order to meet dramatic technological development, presented by Industry 4.0 concept. Gunasekaran, Subramanian and Ngai (2019) say that although quality management became popular in 80's of the last century, enterprises are still struggling with the concept Industry 4.0. Industry 4.0 refers to recent technological advances where internet and supporting technologies serve as a backbone to integrate physical objects, human actors, intelligent machines, production lines and processes across organizational boundaries to form a new kind of intelligent, networked and agile value chain (Schumacher, Erol and Sihn, W., 2016). A comprehensive response on Industry 4.0 in area of quality management is usually titled as Quality 4.0. Javaid et al. (2021) underline that Quality 4.0 is a central principle enabling to harmonize quality management activities with Industry 4.0's new capabilities. The Quality 4.0 is about transforming and improving organizational culture, collaboration, competency and leadership development through the application of technology (Bridges, 2021). Hundreds of articles had been published in this area during last five years analysing various aspects of Quality 4.0 concept. Jacob (2017) looks upon the Quality 4.0 as mixture of new technologies with traditional quality methods to arrive at new optimums in operational excellence, performance, and innovation. Vision and other strategic declarations focused on Quality 4.0 are mentioned as crucial prerequisite (Sony et al., 2021). Some findings from special pilot survey in which 36 quality directors from European firms testified necessity for investments and skills as one of five crucial requirements associated with the Quality 4.0 implementation (Antony, Sony and Cudney, 2020). Santos et al have already identified typical kinds of skills needed for the Quality 4.0 (Santos et al., 2021). Elg et al. (2021) underline necessity in area of cross-functional quality professionals' collaboration with IT specialists and process managers Carvalho et al. (2021) discuss key quality management practices in era of the Industry 4.0. These references are only a few examples of papers dedicated to certain features of the Quality 4.0.

Briefly to say: The Quality 4.0 is really hot and very popular topic at present. We do not want to play down this topic. On the contrary, we are aware of fact that traditional approaches to the quality planning, control, assurance and improvement must be dramatically changed and all quality management systems, regardless they are certified or not, will have to be transformed from the point of their structures, scopes, objectives, infrastructure or people competency. Therefore, authors hope this article could be considered as a small but not useless contribution to such transformation.

2 METHODOLOGY

After necessary literature review, the authors were able to formulate three preliminary findings which led to the creation an original definition of term "closed-loop quality management system". Authors' investigation also aimed to the design of an original framework for CLQMS. Moreover, authors studied three commonly recognized international standards with aim to identify necessary information flows within CLQMS. To discover on what level of readiness for CLQMS implementation Czech production companies are a special questionnaire field survey was provided. 573 Czech production companies from various areas of business were randomly selected for data gathering. Core data gathering was based on a structured questionnaire which could be filled by electronical aid. A response rate was 21.12%. To confirm two research hypotheses, a quantitative and qualitative approach was used to the data processing. Results presented below should be understood as information inputs to the next research activities in area of the Quality 4.0 development throughout the world.

3 LITERATURE REVIEW

Some opinions regarding to the Quality 4.0 were already presented in section Introduction. Now, we focus on progressive approach frequently called mostly as „closed-loop quality management". This approach could be considered as convenient way how to adjust traditional quality management to the new era of digitalisation. The fundamental research question is: was already reached general agreement bearing on terms or structure of the closed-loop quality management?

Unlike Industry 4.0 or Quality 4.0 concepts as a whole, the various issues of the closed-loop quality management are discussed to a lesser extent. Sundaram (2018) declares the belief of organizations that traditional quality management systems are increasingly making a move towards a more future-ready. The closed-loop approach is mentioned there as suitable way. Littlefield (2014) says that closed-loop quality management essentially means connecting quality process or performance data from one area to another, always with the goal of improving quality earlier. Rutter (2021) argues: "closed-loop quality management is the manufacturing business process of proactively making all of the data and processes necessary for ensuring product quality is accessible in one central location, bringing product results from the field back for scope assessment, future issue prevention, and continuous improvement". He also discusses some benefits, including reduced cost of quality. Such issue discussed also Jasurda (2012) despite he has limited closed-loop approach to quality management only to virtual simulations and tolerance analysis software. The economic impact is caused by possibilities when digital technologies and data analytics discover patterns otherwise impossible to detect and take preventive action in early stage of the process (Tomic, 2021). Jardine (2015) declares that for a closed-loop quality system to be truly effective, it must centralize, standardize, and streamline end-to-end business processes and quality data. This can be accomplished most successfully by digitalisation. Goulévitch (2018) presented eight examples of how closed-loop quality management systems should work, including transparency in production processes, traceability, integration with ERP systems, facilitation of lean processes, etc. Speer (2020) holds the view that: "manufacturers must establish procedures for identifying product during all stages of receipt, production, distribution, and installation to prevent failures. This is to ensure that companies are closing the loop between all pre- and post-market activities. A connected system that closes this loop between processes is known as closed-loop traceability". Some papers are dedicated to partial or special issues of the closed-loop management. For example, Franciosa et al. (2020) presents a digital twin framework with closed-loop in-process quality improvement for assembly systems. The closed-loop management in area of acquisition operations and maintenance process is discussed by Kang et al. (2019). But our investigations discovered that majority of articles are oriented at present to the development of the closed-loop management within supply chains. Authors are usually interested in area of non-conformities or returned products with respect of circular economy principles, as well as supplier's social responsibility (see Masouipour, Amirian and Sahrasian, 2017; Chen, Umya and Mancasari, 2020; Almaraj and Trafalis, 2019 and others).

On basis of literature review we are able to formulate three preliminary findings:

1. There is no unified and commonly recognized definition of the term "closed-loop quality management system". Ambiguity of explanations are evident.

2. Authors mostly pay an attention to employment different smart physical devices as sensors, robots, information systems hardware, connectivity means, etc.

3. On the contrary, problems connected with information flows are rather underestimated, despite these flows ought to be counted as vital part of all advanced closed-loop quality management systems!

4 RESULTS

Results presented in this section should be looked upon a response to the three preliminary findings identified above. They are outputs of authors research works.

Above all else, we had to create a definition of the term "closed-loop quality management system". We can launch our conception of it as follows:

Closed-loop quality management system is a part of overall organization's management system based on advanced quality management principles which enables to integrate through comprehensive information flows all quality management processes or performance data with aim to improve the organizational quality.

We do not consider this definition as ultimate declaration. On the contrary, it should be understood as a basis of a future academic discussion and refinement. But this definition has created a starting point for activities, outputs of which will be shown in following sections 4.1 and 4.2.

4.1 The Conceptual Framework of the Closed-Loop Quality Management System

As mentioned above, the information flows should be counted as an essential element of all advanced closed-loop quality management systems. In the upshot, Marsden (2019) confirms this prerequisite as he claims: "The lifeblood of quality management processes is information. Without unique, accurate, timely, complete, accessible, valid and reliable information, then these processes will fail to fully demonstrate performance" Zairi (2019) says: "The plasma of a modern eco-systems is the richness of information and the power of analytics which can guide the eco-system towards its future with more confidence". Companies use a lot of various physical and information devices which should be integrated. Sony et al. (2021) distinguish three forms of integration within the closed-loop quality management in the Quality 4.0 era:

- horizontal (which is along the entire value creation chain),
- vertical (which is alongside the organization's system),
- end-to-end (along the product life cycle).

The quality management systems should concentrate on all types of integration (Sony et al., 2021). To be a framework for Industry 4.0 implementation and assessment, this integration should be considered as a mixture of infrastructure and processes (Lara et al., 2020). Schlechtendahl et al. (2015) says the systems integration is the first step towards Industry 4.0 vision and achieving its goal. Hence, we designed a basic framework of the closed-loop quality management system (see Figure 1) with respect to these arguments.

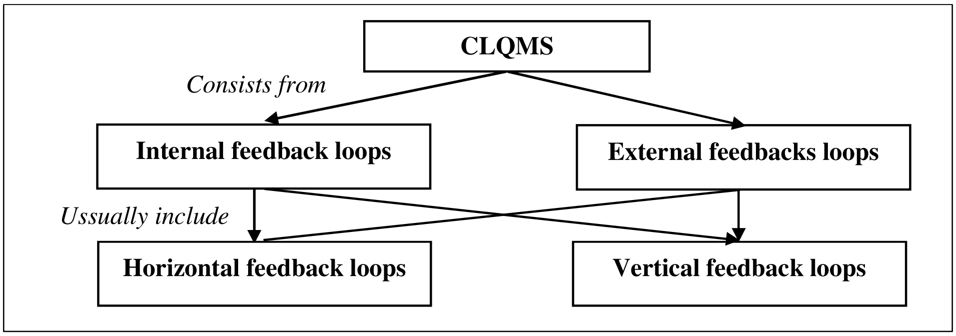

Figure 1 – Basic Framework of CLQMS

Internal feedback loops cover set of information from all organization's processes and performance indicators and it is handed down between process owners usually.

External feedback loops serve as communication tool between organizations' representatives and various external parties such as customers, suppliers, community, etc. The information flows should incorporate above all stakeholders' requirements and perceptions.

Horizontal feedback loops operate within single organizational level and support execution of different processes (production, marketing, logistics, etc.). They should describe how such processes are under control.

Vertical feedback loops integrate different hierarchical levels of the organization. They are located at least two different organizational levels and should enable an organization's strategy, policies and objectives communication, deployment and review.

In practice, these information feedback loops are mutually combinable and operate through an advanced communication means. The authors reviewed three recognized documents in area of current quality management systems: ISO 9001:2015, IATF 16949:2016 and the last version of EFQM Model (EFQM, 2019). 209 of various requirements related to the exchange of information were discovered there. A main distribution of these requirements is presented by Table 1.

Table 1 – Number of Information Feedback Loops Required by Recognized Quality Management Systems Documents (Own Work)

Information feedback loops		**ISO 9001:2015**	**IATF 16949:2016 (in addition to ISO 9001:2015**	**EFQM Model, version 2020 (in addition to ISO 9001:2015 or IATF 16949:2016)**	**Total**
Internal	Horizontal	13	10	2	25
	Vertical	27	33	22	82
External	Horizontal	14	39	37	90
	Vertical	2	6	4	12
Total		56	88	65	209

Some examples of the information feedback loops required by ISO 9001:2015 are shown by Table 2.

Table 2 – Examples of Information Feedback Loops Required by ISO 9001:2015

Information feedback loops		**ISO 9001:2015 requirement**	**Relevant section of ISO 9001:2015**
Internal	Horizontal	• Outputs from organizational context review • Results from internal audits	4.1 9.2.2
	Vertical	• Assignment of the responsibilities and authorities for relevant roles • Information related to measuring equipment that was found to be unfit for its intended purpose	5.3 7.1.5.2
External	Horizontal	• Information related to the quality policy • Information focused on customer complaints	5.2.2 8.2.1
	Vertical	• Knowledge obtained from external sources • Outputs from control and monitoring of the external provider's performance	7.1.6 8.4.3

Demands of IATF 16949:2016 or EFQM Model compared to ISO 9001:2015 basics are obvious. A comprehensive analysis bearing on real state of information flows within companies' quality management systems seem to be a chance for the next research.

4.2 Results of Empirical Field Research

As mentioned in abstract, the research of authors was also aimed to discovering a readiness level of Czech production companies for CLQMS implementation. To reach this aim, the authors performed an empirical field research from November 2020 till March 2021.

Two basic research hypotheses were declared on this purpose:

H_1: Overall readiness level for CLQMS implementation is below-average in Czech production companies.

H_2: Czech production companies in automotive supply chain have achieved a higher level for CLQMS implementation relative the other companies.

573 Czech production companies from various areas of business were randomly selected with support of Albertina database. Data gathering was based on structured questionnaire which could be filled solely by electronical aid. The representative response was obtained from 121 companies, what means a real response rate 21.12%. Table 3 informs about companies' distribution from business area point of view.

Table 3 – Companies' Distribution from Business Area Point of View

Business area	**Number of respondents**
Automotive industry	48
Machinery	20
Textile industry	7
Metallurgy	6
Chemical industry	5
Information technologies	5
Food industry	5
Civil engineering	4
Healthcare industry	4
Electronical industry	3
Other	14
Total	121

The main findings of the research will be presented now through following figures. The horizontal axes in these figures always show a total number of respondents.

The respondents were asked if an implementation of CLQMS is included into company's strategic direction. Figure 2 shows results.

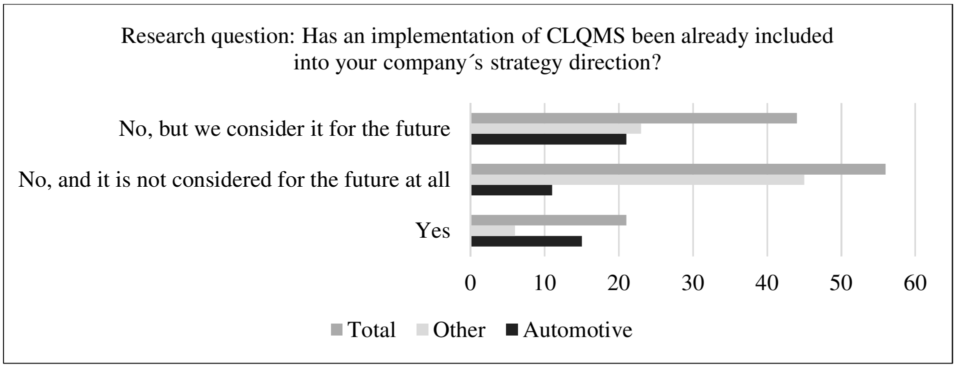

Figure 2 – Implementation of CLQMS as a Part of Czech Production Companies' Strategic Direction

The finding saying that more than 46% of Czech production companies do not consider implementation of CLQMS for the future is not quite positive.

Which stakeholders have already challenged Czech companies to the feedback digitalisation came also under scrutiny. Results are presented by Figure 3.

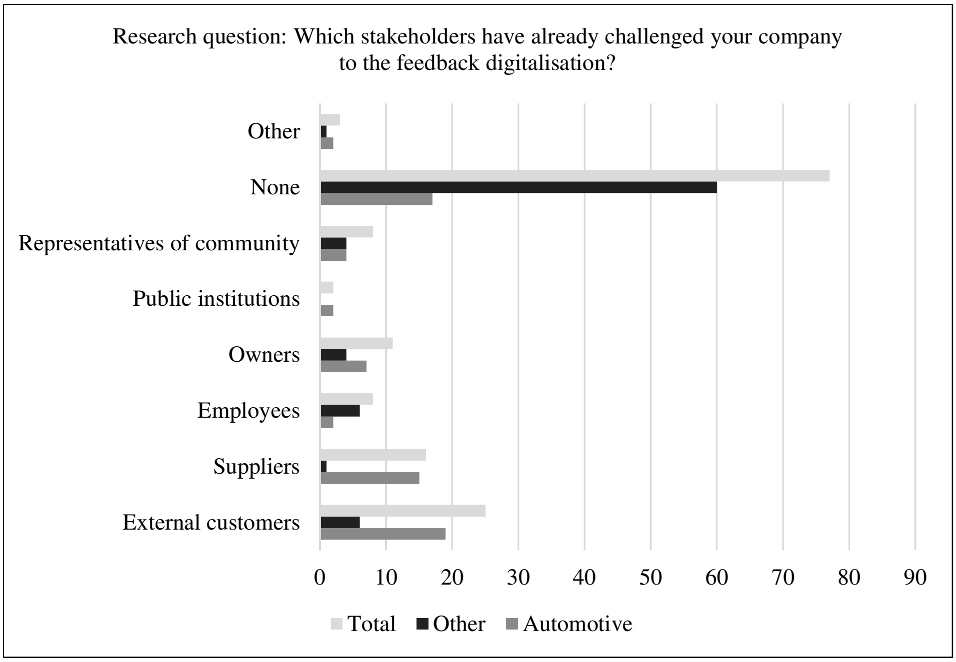

Figure 3 – Stakeholders Call to Czech Production Companies for the Feedback Digitalisation

Certain demands for the feedback digitalisation come from supply chain's links (such as suppliers or customers), especially in area of automotive industry. On the other hand, 77 respondents (what means 63.6 %) declared there is no concern from their stakeholders in this field. It implies that stimulating context for establishing of CLQMS is mostly missing in Czech industries.

Research team was also addressed from what stakeholders Czech companies obtain feedback covering stakeholders' requirements as well as perceptions related to the companies' products. Figure 4 depicts main findings. Practically, all automotive companies gain such feedback from external customers and feedback from staff is not an exception. On the contrary: 15 companies do not get any feedback from stakeholders in spite of they are mostly certified against ISO 9001:2015 standard. This contradiction is reflective of the certification process quality.

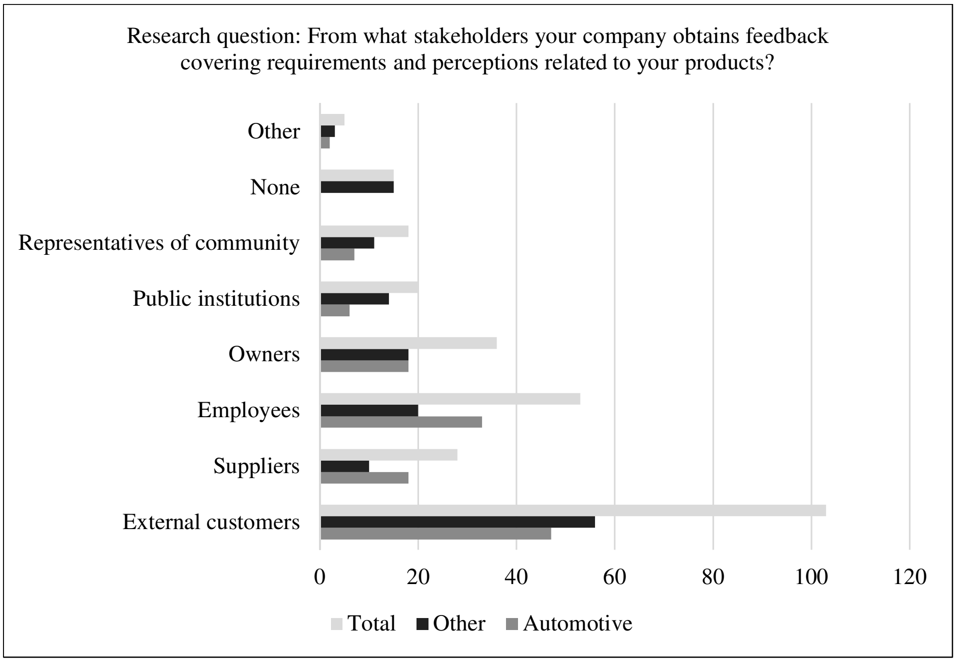

Figure 4 – Feedback Gaining from Stakeholders by Czech Production Companies

Another two questions tried to investigate expected positive effects as well as potential barriers associated with possible CLQMS implementation. Tables 4 and 5provide main findings. While opinions bear on positive effects of CLQMS implementation are relatively similar at automotive and other industries, perception of potential barriers is substantially different: production companies which are active outside the automotive supply chain perceive some barriers more urgently. Difficult co-operation and communication between quality and IT professionals poses the only exception in this case.

Table 4 – Potential Effects of CLQMS Implementation

No.	Description of potential effect	Quantity of responses		
		Automotive	Other	Total
1.	Creation of a long-term competitive advantage	31	38	69
2.	More exacting identification of the stakeholders requirements	30	38	68
3.	Reduction of products' time to market	22	36	58
4.	Enforcement of quality assurance across company processes	24	27	51
5.	Rapid interventions when quality deviations occur	30	21	51
6.	Support be-directional connections of people and processes	23	25	48
7.	Support early warning concept at design and development	19	19	38
8.	Efficient risks and opportunities management	15	17	32
9.	Better people involvement in decision-making activities	9	22	31
10.	Optimization of quality related costs	17	11	28
11.	Possibility of mass products' customization	20	4	24
12.	Enhancement of products compliance towards Six Sigma performance	8	3	11

Table 5 – Potential Barriers of CLQMS Implementation

No.	Description of potential barrier	Quantity of responses		
		Automotive	Other	Total
1.	Considerable time and capital investment	36	60	96
2.	Lack of financial resources	22	38	60
3.	Top managers mental stereotypes and unwillingness	15	34	49
4.	Necessity of a new people knowledge and competence	16	32	48
5.	Absence of long-term quality strategic direction	16	31	47
6.	Difficult co-operation and communication between quality and IT professionals	14	10	24

5 CONCLUSIONS

On basis of our investigation the following conclusions should be in place:

- The field research confirmed both research hypotheses declared in section 4.2. The current readiness of Czech production companies for CLQMS implementation is insufficient, despite the automotive sector reaches a higher level of such readiness.
- The finding saying that nearly 50% of Czech production companies do not consider implementation of CLQMS for the future is warning signal with regard to the future development.
- Respondents are aware of important positive impacts of CLQMS implementation, especially in area of companies' agility and overall performance.
- Due to potential barriers of CLQMS implementation, the current perception of Czech managers is not far away findings presented by Küpper et al. (2019) as a results of special study conducted by Boston Consulting Group. Because this study confirmed that technology is the only one piece of a broader quality transformation that must also focus on people and skills.
- On the whole: The Quality 4.0 concept is in progress, as well as development of the closed-loop quality management systems.

We are sure the Czech production companies will have not afford to ignore the Quality 4.0 concept as, perhaps, the quality management transformation is not only opportunity, but strong requirement how to adapt any company to the new industrial reality.

Authors see three key prerequisites how to improve the readiness for CLQMS at Czech companies:

1. To declare, implement and develop their vision focused on CLQMS and clearly communicate this vision internally and externally.
2. To determine and release the resources needed for CLQMS establishing, maintenance and continuous improvement.
3. New skills acquiring for all relevant roles and massive support of mutual cooperation between quality and information technology professionals.

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Conceptualization, J.N. and D.V.; Methodology, J.N. and D.V.; Validation, D.V.; Formal analysis, J.N. and D.V.; Investigation, J.N. and D.V; Resources, J.N.; Data curation, J.N. and D.V; Original draft preparation, J.N. and D.V; Review and editing, J.N. and D.V; Visualization, J.N. and D.V.; Supervision, J.N.; Project administration, D.V.; Funding acquisition, J.N. and D.V.

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.

How Can the Check Standard Influence Measurement Process Capability

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ABSTRACT

Purpose: The main objective of the paper is an analysis of the behaviour of capability indices under different conditions. It is assumed that the metrological properties of a check standard are correct, however, the uncertainty of the check standard affects the evaluation of the measurement process capability. The paper analyses individual cases of the influence of the check standard bias and its influence on the measurement process capability.

Methodology/Approach: Statistical analysis of both the measurement process and the check standard is provided at the beginning. Development and analysis of possible cases, when the bias of a check standard affects the calculated capability index of a measurement process follows.

Findings: The paper confirmed the theoretical assumption that a bias of a check standard can affect the calculated capability index of a measurement process, thus shifting the judgment on the measurement process capability.

Research Limitation/Implication: The paper is based on the theoretical assumptions of the measurement process capability as well as on the analysis of the possible behaviour of a respective check standard.

Originality/Value of paper: The paper clarifies that several particular and specifically selected cases of bias of a check standard may affect the resulting capability index negatively/positively, which may lead to inaccurate decisions on measurement process capability. This is confirmed by simulations of a biased check standard, clearly visualizing the shifts in capability indices.

Category: Research paper

Keywords: measurement process; capability index; measurement uncertainty; check standard; probability distribution

1 INTRODUCTION

Capability indices are significantly used in the management of production processes. Many studies in this area are elaborated (Pearn and Kotz, 2006; Pearn and Liao, 2006; Baral and Anis, 2015; Grau, 2013; Haq et al., 2015; Malek et al., 2017; IST/SEMATECH, 2012; Bordignon and Scagliarini, 2002; Kotz, Pearn and Johnson, 1993; Montgomery, 2004). Further references are given in the cited texts. Relyea (2011) lists many issues related to the metrological characteristics of measurement devices and the competence of measurement processes. Issues related to digitalization in industrial and societal infrastructures are also addressed by (Santos et al., 2021), which is also closely related to process capability.

Capability indices compare the required (prescribed) precision of the measurement process (MP) with real process variability and deflection (bias). In praxis the so-called first generation of the indices: C_g and C_{gk} are used. The calculated values of these indices should be higher than 1.33 to claim that the measurement process is suitable for the process it has been created for.

The use of capability indices makes it possible to avoid controlling the suitability of the measurement process by means of uncertainties determined according to (JCGM 100:2008; JCGM 102:2011). GUM, which is challenging since the sources of uncertainty and their valuation needs to be determined. The use of capability indices is conditioned using so-called check standard (CS). The exact "true" nominal value of the CS is not known. We can only estimate its value with a certain uncertainty. This CS uncertainty under 10% of the overall process uncertainty is usually neglected, similarly like the measurement uncertainty in manufacturing processes. This assumption assumes that the error of CS during a repeated measurement is within the limits of the expanded uncertainty and is therefore random. Unfortunately, during the repeated measurements, the check standard can develop a bias under some specific conditions. The Influence of the CS uncertainty was also analysed by the authors in (Kureková, 2017; Palenčár et al., 2018). There was thesis, which also proposes usage of the capability indices of next generations in measurement process analysis (Palencar, 2017). In the upcoming sections of this publication the effect of such bias will be shown together with the evidence that a CS uncertainty with a value less than 10% of overall MP uncertainty can have a considerable effect on the final value of the capability indices and consequently on the final assessment of the capability of the measurement process.

2 THEORETICAL BASIS

Assume that probability distribution of the measurement process whose distribution we want to determine, is $X{\sim}N(\mu,\sigma^2)$, probability distribution of the check standard is $X_{\mathrm{CS}}{\sim}N(\mu_{CS}=\hat{\mu}_{CS}+\delta_{\mathrm{CS}},\sigma_{\mathrm{CS}}^2)$ and measurement result Y, obtained by measurement of the check standard, is $Y{\sim}N(\mu_Y=\mu+\delta_{CS},\ \sigma_Y^2=$

$\sigma^2 + \sigma_{CS}^2)$, where μ is the mean value of the measurement process, σ is standard deviation of the measurement process, $\hat{\mu}_{CS}$ is the estimate of mean value from measurements of CS, δ_{CS} is a systematic part of the check standard deviation, σ_{CS} is characteristics of the random part of the check standard deviation.

Sometimes its estimate is known as $\hat{\sigma}_{CS} = u_{A_{CS}}$, which is standard type A uncertainty of the CS. Assumption of normality is not stringent, practically speaking, all that is required is that the distribution of measurements be bell-shaped and symmetric.

Let us define parameter λ_A as a relative variation of the control standard value in the control measurements there on due to the required uncertainty of the measurement process:

$$\lambda_A = \frac{2\sigma_{CS}}{U}, \tag{1}$$

where U is the overall (required) uncertainty of the measurement process, $\sigma_{CS} = u_{A_{CS}}$, which is standard uncertainty type A of the CS, λ_A represents the relative variation of the CS value in the control measurements related to the required measurement process uncertainty.

When we assess the measurement process capability, we need the most unfavorable situation to consider. This is when the CS error is equal the value of the U_{CS} and at the same time will be aiming opposite direction like the true deflection of the MP.

3 CAPABILITY INDEX C_g AND UNCERTAINTY OF THE CHCECK STANDARD

Capability index C_g is defined as (Pearn and Kotz, 2006; Grau, 2013):

$$C_g = \frac{USL - LSL}{4\,\sigma} = \frac{U}{2\,\sigma}. \tag{2}$$

The empirical capability index C_g^Y is obtained by the substitution μ for μ_Y and σ for σ_Y. Then the relationship between the actual process capability index C_g and the empirical capability index C_g^Y will be:

$$C_g^Y = \frac{U}{2\,\sigma_Y} = \frac{U}{2\sqrt{\sigma^2 + \sigma_{CS}^2}} = \frac{U}{2\sigma}\frac{1}{\sqrt{1 + \sigma_{CS}^2/\sigma^2}} = C_g \frac{1}{\sqrt{1 + \lambda_A^2 C_g^2}} \tag{3}$$

and because:

$$\frac{\sigma_{CS}}{\sigma} = \frac{\sigma_{CS}}{U}\frac{U}{\sigma} = C_g \lambda_A\,, \tag{4}$$

then also:

$$\frac{C_g^Y}{C_g} = \frac{1}{\sqrt{1 + \lambda_A^2 C_g^2}}. \tag{5}$$

Figure 1 shows dependence of the ratio C_g^Y / C_g on λ_A.

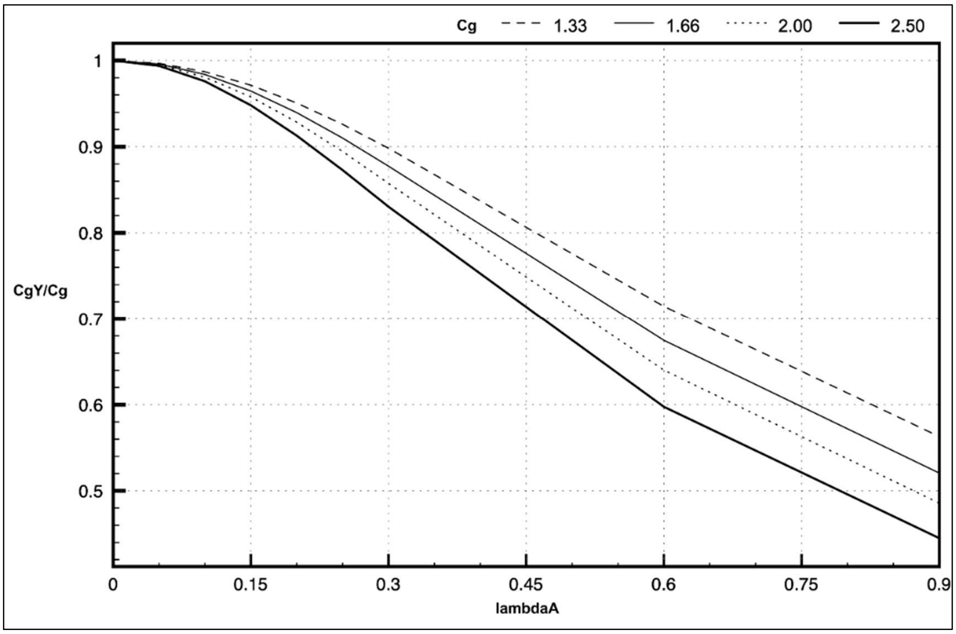

Figure 1 – Ratio of the Experimental Capability Index C_g^Y to the Actual Capability Index C_g

Based on (5) it is valid that for $\lambda_A C_g < 1$.

$$C_g^Y = \frac{C_g}{\sqrt{1 + \lambda_A^2 C_g^2}} \Rightarrow C_g = C_g^Y \frac{1}{\sqrt{1 - \lambda_A^2 {C_g^Y}^2}}. \tag{6}$$

The calculated capability index C_g^Y is always smaller than the actual capability index C_g. That is, if the calculated index C_g^Y is satisfactory, the actual index C_g is satisfactory as well. Also, knowledge of the uncertainty of the control standard caused by the variation of the control standard values, obtained when the control standard is used, allows evaluation of a capability index. In assessing the capability of a measurement process, the relationship (6) enables correcting the capability index C_g by a correction factor of $\frac{1}{\sqrt{1-\lambda_A^2 {C_g^Y}^2}}$, if λ_A is known. However, the knowledge of λ_A may not be simple, so let's settle for the fact that the calculated capability index C_g^Y is always smaller than the actual capability index C_g.

For measured values Y_i, the capability index C_g^Y will be calculated from empirical data:

$$\hat{C}_g^Y = \frac{U}{2s_Y}, \tag{7}$$

where $s_Y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$ and $\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$ are maximum plausible estimates of σ_Y^2 and μ_Y.

4 CAPABILITY INDEX C_{gk} AND UNCERTAINTY OF THE CHCECK STANDARD

Capability index C_{gk} is defined as (Pearn and Kotz, 2006; Grau, 2013):

$$\begin{aligned} C_{gk} &= min\left(\frac{USL - \mu}{2\sigma}, \frac{\mu - LSL}{2\sigma}\right) \\ &= min\left(\frac{(\hat{\mu}_{CS} + U) - \mu}{2\sigma}, \frac{\mu - (\hat{\mu}_{CS} - U)}{2\sigma}\right). \end{aligned} \tag{8}$$

If we denote $\delta = \mu - \hat{\mu_{CS}}$, where μ is the mean value of the MP and the $\hat{\mu}_{CS}$ is the estimate of mean value from measurements of CS (values from CS certificate), in the case of symmetrical uncertainty of the check standard, then:

$$C_{gk} = \frac{U - |\delta|}{2\sigma} = C_g(1 - v), \tag{9}$$

where $v = \frac{|\delta|}{U}$ is the relative bias of the measurement process with respect to the desired expanded uncertainty of the measurement process.

Empirical capability index C_{gk}^Y is obtained by replacing μ by μ_Y and σ by $\sigma_{Y.}$ For measured values Y_i, the capability index $\hat{C}_{gk}^Y$ will be calculated from empirical data:

$$\hat{C}_{gk}^Y = \frac{U - |\bar{Y} - \hat{\mu}_{CS}|}{2s_Y}, \tag{10}$$

where $s_Y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$ and $\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$ are maximum plausible estimates of σ_Y^2 and μ_Y.

If we denote the parameter $\gamma = \frac{|\delta_{CS}|}{U}$ as the relative systematic error (bias) of the check standard with respect to the required extended uncertainty of the measurement process, following cases may be considered:

1. The bias of the check standard γ and the bias of the measurement process v act against each other:

$$C_{gk}^{Y} = min\left(\frac{(\hat{\mu}_{CS} + U) - (\mu - |\delta_{CS}|)}{2\sqrt{\sigma^2 + \sigma_{CS}^2}}, \frac{(\mu - |\delta_{CS}|) - (\hat{\mu}_{CS} - U)}{2\sqrt{\sigma^2 + \sigma_{CS}^2}}\right). \tag{11}$$

   a) For $\gamma \leq$ v is valid:

$$\begin{aligned} C_{gk}^{Y} &= \frac{U - (|\delta| - |\delta_{CS}|)}{2\sqrt{\sigma^2 + \sigma_{CS}^2}} = C_g \frac{1 - v + \gamma}{\sqrt{1 + \lambda_A^2 C_g^2}} = C_{gk} \frac{1 - v + \gamma}{(1 - v)\sqrt{1 + \lambda_A^2 C_g^2}} \\ &= C_{gk}\left(1 + \frac{\gamma}{1 - v}\right)\frac{1}{\sqrt{1 + \lambda_A^2 C_g^2}}. \end{aligned} \tag{12}$$

   b) For $\gamma \geq$ v is valid:

$$\begin{aligned} C_{gk}^{Y} &= \frac{U - (|\delta_{CS}| - |\delta|)}{2\sqrt{\sigma^2 + \sigma_{CS}^2}} = C_g \frac{1 + v - \gamma}{\sqrt{1 + \lambda_A^2 C_g^2}} = C_{gk} \frac{1 + v - \gamma}{(1 - v)\sqrt{1 + \lambda_A^2 C_g^2}} \\ &= C_{gk}\left(1 + \frac{2v - \gamma}{1 - v}\right)\frac{1}{\sqrt{1 + \lambda_A^2 C_g^2}}. \end{aligned} \tag{13}$$

2. The bias of the check standard γ and the bias of the measurement process v act in the same direction:

$$\begin{aligned} C_{gk}^{Y} &= \frac{U - (|\delta_{CS}| + |\delta|)}{2\sqrt{\sigma^2 + \sigma_{CS}^2}} = C_{gk} \frac{1 - v - \gamma}{(1 - v)\sqrt{1 + \lambda_A^2 C_g^2}} \\ &= C_{gk}\left(1 - \frac{\gamma}{1 - v}\right)\frac{1}{\sqrt{1 + \lambda_A^2 C_g^2}}. \end{aligned} \tag{14}$$

Let us define parameter h:

1. First case, when the bias of the CS γ and the bias of the MP v act against each other.

   a) For $\gamma \leq v$ is valid $h = \frac{\gamma}{1-v}$.

   b) For $\gamma \geq v$ is valid $h = \frac{2v-\gamma}{1-v}$.

2. Second case, when the bias of the CS γ and the bias of the MP v act in the same direction $h = -\frac{\gamma}{1-v}$.

Then it is valid:

$$C_{gk}^{Y} = C_{gk} \frac{1}{\sqrt{1+\lambda_A^2 C_g^2}}(1+h)\,, \tag{15}$$

respectively,

$$C_{gk} = C_{gk}^{Y} \frac{1}{\sqrt{1-\lambda_A^2 C_g^{Y\,2}}} \frac{1}{1+h}, \tag{16}$$

and the ratio:

$$\frac{C_{gk}^{Y}}{C_{gk}} = \frac{1}{\sqrt{1+\lambda_A^2 C_g^2}}(1+h)\,. \tag{17}$$

If deviation of the check standard acts against the deviation of the measurement process, also $\gamma \leq 2v$, then empiric index C_{gk}^{Y} will be bigger than the actual one.

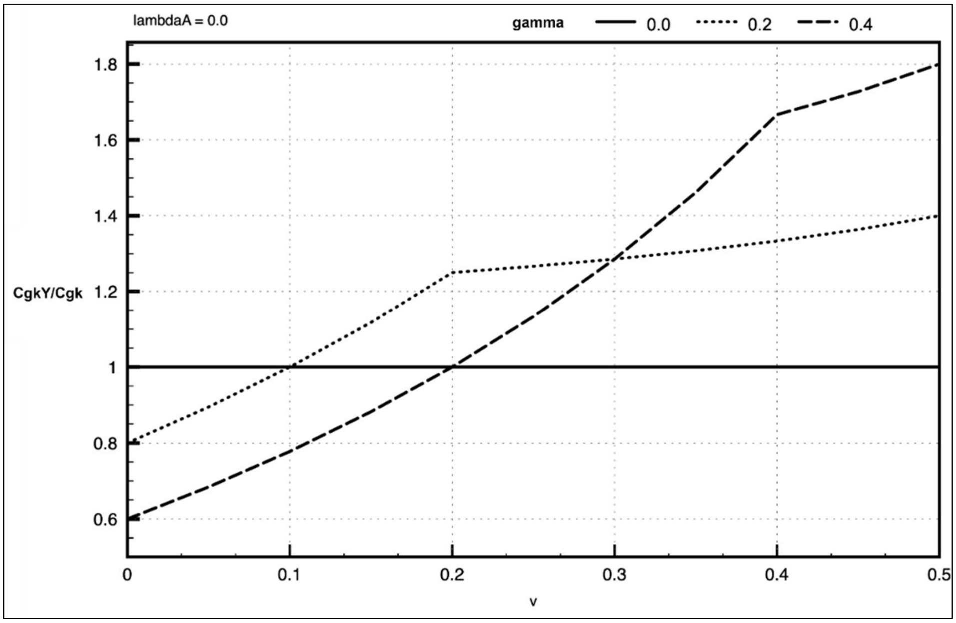

Figure 2 – Ratio of Experimental Capability Indices to the Actual Ones for $\lambda_A = 0$

Figure 2 shows the ratio of empirical and actual capability index C_{gk}^{Y}/C_{gk} for $\lambda_A = 0$ in case bias of the check standard γ and bias of the measurement process v act against each other. The graph allows the interpretation of the empirical capability index values obtained.

We can see that:

i. for $v < 0.5\,\gamma$, the empirical capability index is smaller than the actual one and decreases with decreasing bias of the MP,

ii. for $v = 0.5\,\gamma$, the empirical capability index is identical to the actual one,

iii. for $v > 0.5\,\gamma$ is empirical capability index bigger than the actual one and with increasing v against γ the empirical capability index rises in comparison with the actual one,

iv. the point $v = \gamma$ represents a value, from which the empirical capability index increases slower with increasing bias of the measurement process.

The relationship (15) indicates that the empirical capability index may be either smaller or larger than the actual capability index. If the check standard bias acts against the bias of a measurement process and $\gamma \le 2v$, the empirical capability index C_{gk}^{Y} will be greater than the actual one. The correction factor for determining the actual capability index C_{gk} is $\frac{1}{\sqrt{1-\lambda_A^2 C_g^{Y\,2}}}\frac{1}{1+h}$. This correction assumes knowledge of the components of the uncertainty of the check standard, i.e., the proportion of uncertainty caused by the variation in check standard values when used and the bias of check standard when used. This we called a combined approach which is a combination of the statistical approach and the conservative approach. Here we consider the most unfavorable case, i.e., $|\delta_{CS}| = U_{CS} - 2\sigma_{CS}$.

If we assume that uncertainty of the check standard arises mainly from random fluctuations of check standard values, when it is used (control of measurement process capability), then γ is considered as negligible and the whole expanded uncertainty of the check standard U_{CS} is substituted for $2\sigma_{CS}$ to calculate λ_A. This we called statistical approach.

If we assume that uncertainty of the check standard arises mainly from the systematic deviation of check standard values, when it is used (control of measurement process capability), then λ_A is considered as negligible and the whole expanded uncertainty of the check standard U_{CS} is substituted for δ_{CS} to calculate γ (relative deviation of the check standard). This we called conservative approach.

Table 1 – Empirical Capability Index C_{gk}^{Y} Values for Different γ and for the Actual Capability Index $C_{gk} = 1.33$ (Conservative Approach)

γ	v							
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
0.02	1.30	1.36	1.36	1.37	1.37	1.38	1.40	1.42
0.04	1.28	1.39	1.40	1.41	1.42	1.44	1.46	1.51
0.06	1.25	1.42	1.43	1.44	1.46	1.49	1.53	1.61
0.08	1.22	1.45	1.46	1.48	1.51	1.54	1.60	1.68
0.10	1.20	1.48	1.50	1.52	1.55	1.60	1.66	1.77
0.12	1.17	1.45	1.53	1.56	1.60	1.65	1.73	1.86
0.15	1.13	1.40	1.59	1.62	1.66	1.74	1.83	2.00
0.20	1.06	1.33	1.66	1.71	1.77	1.86	2.00	2.22

Table 2 – Empirical Capability Index C_{gk}^{Y} Values for Different Ratios h and for the Actual Capability Index $C_{gk} = 1.33$ (Conservative Approach)

h	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
C_{gk}^{Y}	1.33	1.46	1.60	1.73	1.86	2.00	2.13	2.26

Table 1 and Table 2 provide the minimum values of empirical capability indices C_{gk}^{Y}, required to declare a measurement process is capable, i.e., the actual capability index C_{gk} > 1.33. For $v < \gamma \leq 2v$, the empirical capability index is still greater than the actual index but decreases with increasing bias of the check standard. For $\gamma > 2v$ the empirical capability index already provides smaller value than the actual one. The correction factors for the individual cases are given in Table 3.

Table 3 – Correction Factors for Different Approaches of Capability Indices Assessment for $\lambda_A C_g < 1$

	Correction factors		
Capability index	Combined approach	Statistical approach	Conservative approach
C_g	$\frac{1}{\sqrt{1-\lambda_A^2 {C_g^Y}^2}}$	$\frac{1}{\sqrt{1-\lambda_A^2 {C_g^Y}^2}}$	1
C_{gk}	$\frac{1}{1+h}\,\frac{1}{\sqrt{1-\lambda_A^2 {C_g^Y}^2}}$	$\frac{1}{\sqrt{1-\lambda_A^2 {C_g^Y}^2}}$	$\frac{1}{1+h}$

5 EXAMPLE

Let us suppose measurement of outer dimensions and diameters by a digital micrometer (measuring range 25-50 mm), having a maximum permissible error of 0.001 mm.

Requirements put on measurement process are expressed by an expanded uncertainty $U = 0.01$ mm. The expanded uncertainty of the check standard is $U_{cs} = 0.0008$ mm, which stands for 8% of overall MP uncertainty. Measurement on check standard yields to the bias of $\delta = -0.0054$ mm with standard deviation $\sigma = 0.00152$ mm.

Case 1: Let us assume, that we have the information that standard uncertainty, connected with fluctuation of data of the check standard, is $u_{A_{CS}} = \sigma_{CS} = 0.000076$ mm, so we can use combined approach. Then ratio $\lambda_A = 0.015$ and parameter $h = 0.14$.

Case 2: Let us assume, that we have no information about CS uncertainty, so we use conservative approach, which represents worst case scenario. Then we assume that systematic part of the CS deviation $\delta_{CS} = U_{cs} = 0.0008$ and parameter $h = 0.17$.

Table 4 – Empirical Capability Indices Values Corrected by Combined and Conservative Approach

Empirical capability indices	$C_g^Y = 3.29$	$C_{gk}^Y = 1.51$
Corrected capability indices		
Combined approach	$C_g = 3.29$	$C_{gk} = 1.33$
Conservative approach	$C_g = 3.29$	$C_{gk} = 1.29$

Table 4 introduces values of empirical capability indices, corrected by combined approach and by conservative approach. Empirical capability indices declare that the measurement process is satisfactory. The actual combined capability index also indicates the measurement process capable, although the actual index is less than empirical. If we are not sure that the data fluctuations measured on the check standard are equal to the declared standard deviation of the check standard, we would have to use a conservative capability index and as shown in Table 4, we are not sure that the measurement process is satisfactory.

6 CONCLUSION

In practice, it is generally assumed that the uncertainty of the control standard in assessing the capability indices of measurement processes can be neglected. However, there may be situations where this is not the case. In this paper, we examined how uncertainty of the control standard affects capability indices. This may be particularly important at lower capability indices values, where data due to the uncertainty of the control standard indicate that the process is capable and in fact it may not be true. We can see that the automatic non-consideration of CS uncertainty U_{CS}, even at a value of less than 10% of the overall process uncertainty U, especially for small type A uncertainty, can lead to incorrect conclusions (see Figure 2 and Table 2 and Table 3). This applies to the capability index values C_{gk} approaching 1.33 and precisely at that time the neglect of the CS uncertainty can lead to improper evaluation of the measurement process capability. We see that the decisive role is played by parameter h, which represents the deflection relation CS and deflection MP. We have provided a correction factor that enables correcting the empirical value of the capability index and thus avoid a possible incorrect evaluation of the measurement process capability.

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CONFLICTS OF INTEREST

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Developing a Quality 4.0 Maturity Index for Improved Business Operational Efficiency and Performance

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ABSTRACT

Purpose: Technological advances and increased environmental turbulence require a transition in quality management. The study aimed at developing a Quality 4.0 maturity index for improved business operational efficiency and performance.

Methodology/Approach: This conceptual paper introduces a theoretical business evaluative model that allows an integrated analysis of technology-driven, quality management dimensions. The model is based on theoretical and empirical information and describes Quality 4.0 business analysis by a theoretical central business dimensional concept, formal statistical analytical methods and uses these data to assign a maturity index score to the business.

Findings: The study builds the Quality 4.0 maturity index following the analysis of seven continuous quality improvement dimensions. The maturity of these dimensions in the business is assessed with a five-point maturity level. The effectiveness of the index should be confirmed with fit as covariation and a composite score for the level of Quality 4.0 maturity.

Research Limitation/Implication: The research is based on theory and has not been validated with empirical data. It is recommended that a validation study be conducted based on the approach and guidelines provided in the paper.

Originality/Value of paper: The study helped develop a theoretical aspect of total quality management during an era of the fourth industrial revolution. It also aimed at practically benefiting a business by focussing on improved business capacity and capability to mitigate the environmental turbulence associated with pandemics. The paper provides novel work, as it describes one of the first Quality 4.0 maturity index models that may be used to improve business.

Category: Conceptual paper

Keywords: quality 4.0; maturity index; operational efficiency; performance

1 INTRODUCTION

Customer requirements are constantly changing, making it challenging to maintain a high standard of quality service provision and customer satisfaction (Gold and Pray, 1999; Bergman and Klefsjö, 2010; Felix, 2015). Changes in socio-economic conditions drive this higher expectation of customisation, technological change and changing societal imperatives (Mihajlović and Koncul, 2016). This requires firms to analyse the deployment of new customer requirements, solutions and behaviour and assess the competitive landscape and the focal business relationships with other customers and suppliers in the value chain (Biggemann et al., 2013). This highlights how the forces that drive customer and supplier interests and incentives to collaborate on customer solutions can change over time, altering the purpose and scope of solutions and increasing the risk of service failure. Customers identify problems and suppliers respond based not only on the viability of the customer-specific solution but also on their assessment of future solutions in a broader market allowing suppliers to then seek standardised, successful solutions across markets. Numerous firms still suffer from quality issues critical to meeting this changing demand, as evidenced by numerous product recalls across several industries (Magno, 2012; Bernon et al., 2018; Gunasekaran, Subramanian and Ngai, 2019). Chang, Ellinger and Blackhurst (2015) argued that these recalls can negatively impact a business' performance, erode brand equity, tarnish its reputation, create panic among customers to result in revenue and market share losses. This can have a short-term impact on shareholder wealth and long-term effects on supply chain disruptions (Zhao, Li and Flynn, 2013). This has created a continuous debate on whether the traditional quality management strategies and methodologies respond effectively to changes in product development stages, cycle time shortening and staff efforts to meet demand and consumer expectations (Gunasekaran, Subramanian and Ngai, 2019).

Research on Quality 4.0 has gained traction in the last five years, driven by technological advances which increased the accessibility of the Fourth Industrial Revolution (4IR) technologies, as well as the COVID-19 pandemic which changed the face of society and the workplace (Sony and Aithal, 2020; Broday, 2022). Together with such research, it is critical to also develop a Quality 4.0 maturity assessment model that can be employed to help improve operational efficiency and business performance. This is particularly important within developing countries such as South Africa, where there are several barriers to the implementation of the 4IR (Mtotywa et al., 2022).

2 EVOLUTION OF QUALITY MANAGEMENT TO QUALITY 4.0

Quality management has evolved over decades with four major paradigm shifts together with incremental changes observed during these periods (Weckenmann, Akkasoglu and Werner, 2015; Carnerud and Bäckström, 2021). Initially, the focus for quality management was on inspections to detect a defect or deficiency in the product, after which it evolved to include quality control, where efforts were made to eliminate the cause of the defects. With the development in quality management driven by some of the quality gurus such as Deming, Juran, Ishikawa, Crosby and others, the quality management focused on quality assurance and then total quality management (Evans, 2017) focussing on quality for the whole firm (Sader, Husti and Daroczi, 2022).

2.1 Contextualising Total Quality Management

Total quality management (TQM) was developed over several decades, with authors such as Deming, Juran and Crosby providing much of the seminal work to significantly impact development with regards to, amongst others, the focus and approach to the customer, TQM measurement and leadership commitment (Zairi, 2013; Evans, 2017).

Total quality management is used in all areas to improve processes and optimise business and is a recognised, sustainable application for competitive advantage (Talib, 2013). The TQM is a quality-focused management method based on the engagement of all employees and it's aim is for long-term success by prioritising the customer and offering benefits to the organisation and society. Goetsch and Davis (2014) contextualised total quality as a three-legged stool with a customer focus as the 'seat' and the 'legs' being measures, people and processes. The measures are statistical processes, benchmarking and quality tools, while people constitute the base upon which the quality is built, expected and empowered to effectively ensure total quality in the firm, while the processes aimed at continual improvement and are driven by the principle of 'good enough is never good enough' due to changing demand and requirements of customers. This highlights that, over the years, quality management has demonstrated an exceptional ability to update and evolve in response to the context and the needs of customers, firms and the operating environment (Fundin et al., 2020).

Literature shows that six to ten dimensions of TQM are associated with improving efficiency and performance in organisations. These dimensions include customer focus, committed leadership or management commitment, continuous process and systems improvement, participation of all employees, training, communication, supplier relationship, management by facts, strategic focus on quality as a source of competitive advantage as well as benchmarking (Bergman and Klefsjö, 2010; Psomas and Fotopoulos, 2010; Agus and Hassan, 2011; Aquilani et al., 2017; Evans, 2017; Bouranta et al., 2019; Fayyaz, 2021).

Traditionally, TQM was developed as an organisational measure (Prajogo and Hong, 2008; Mosadeghrad, 2013; Deshpande, 2019). However, research has shown the applicability of the TQM at the level of the individual with in-depth knowledge of process or organisation such as subject matter experts, process owners, internal or external consultants with relevant expertise as well as senior management (Prajogo and Cooper, 2017; Alweteed, 2018). This is possible as TQM is essentially a way of organising and involving the whole organisation;

every department, every activity, every single person at every level (Oakland, 1989). This was further explained by Morgan and Murgatroyd (1997) who noted that the "total" element of TQM indicates that every organisational member is active in quality improvement processes.

2.2 Development of Quality 4.0

With the technological advances and the advent of the 4IR, the focus on quality shifted toward Quality 4.0. While "Quality 4.0" is still in its infancy and no standard has been established, some authors have already addressed its implications within an industry and business firm context (Efimova and Briš, 2021). Several studies on Quality 4.0 have associated it with the impact of technology on TQM (Sader, Husti and Daróczi, 2019; Chiarini, 2020; Nenadál, 2020; Carvalho et al., 2021). Quality 4.0 is founded on empirical learning, empirical knowledge discovery as well as real-time data generation, collection and analysis to enable intelligent operations decisions (Nenadál, 2020; Rifqi et al., 2021; Broday, 2022). Quality 4.0 ensures that pertinent information is communicated continuously via the system. Thus, a delicate balance of digital confidence is essential to assure data protection and customer identity confidentiality. Regarding validation, artificial intelligence (AI) and machine learning is utilised to reflect beneficial effects on industrial operations (Javaid et al., 2021). It is applicable at different levels, from an individual level to the operations and business level, as well as the external operating environment.

3 QUALITY 4.0 MATURITY ASSESSMENT MODEL

The Quality 4.0 maturity assessment model builds the Quality 4.0 maturity index upon seven continuous, quality improvement dimensions. These seven dimensions are assessed using a 28-item scale. The maturity of these dimensions in the business is assessed and the effectiveness of the index is confirmed with fit as covariation and and a composite score for the level of Quality 4.0 maturity.

3.1 Dimensions of Quality 4.0

The dimensions of the Quality 4.0 model are grounded on total quality within the context of industry 4.0 and are enhanced by other quality tools and approaches such as lean-six sigma. Quality 4.0 should comprise not only quality digitalisation but also quality technologies, processes as well as people who influence digitisation. In the past, quality management was conducted through data-driven decision-making, but today, evidence-based decision-making is increasingly significant and the role of analysts is highlighted due to the collection of massive data in real-time (Jacob, 2017; Lee, Lee and Kim, 2019). As such, there are seven dimensions that were developed in this conceptual paper which are critical for improved operational efficiency and business performance of the Quality 4.0 model. These are management commitment to technology and innovation-driven operations, customer focus that enhances the voice of the customer, quality for strategy and competitive advantage, operational environment benchmarking, forecasting and future prediction, employee involvement and empowerment, process and systems integration and management and root cause analysis of operations disturbances and sustainable solution.

3.1.1 Management commitment to technology and innovation

The first dimenson is management commitment to technology and innovation (MC). There is general consensus within the quality management sphere that management commitment to quality management is critical. This is evident from the approaches proposed by Deming, Juran and Crosby, amongst others (Goestch and Davis, 2014; Evans, 2017). The management role remains critical with the changing quality environment and the implementation of Quality 4.0. With Quality 4.0 grounded on the technologies of the 4IR (Rifqi et al., 2021; Broday, 2022), management must be committed to technology and innovation, with this journey demanding a mental and cultural shift. Thus, top management is a crucial enabler of Quality 4.0 and individuals must be receptive to external ideas and willing to share their knowledge. By displaying dedication and support, senior management is vital to overcoming the opposition of individuals who oppose the implementation of innovation (Igartua, Garrigós and Hervas-Oliver, 2010).

Management must drive technology and innovation strategy and culture, clarify how the value will be developed, supply the innovation implementation team with a budget and assistance and monitor and evaluate results (Mortara et al., 2009; Huizingh, 2011). The importance of top management commitment and support is because it affects innovation, product as well as and process innovation (Al Shaar et al., 2015). Moreover, top management support influences the organisational structure and information technology (IT) synergy to directly affect the company's technology adoption and operational performance. Fernaldi, Hotlan and Selvie (2020) concluded that top management commitment has an impact on operational performance using information technology and supply chain management practices. This is because management has shown its commitment by providing the human resources needed to support the use of technology, which is provided according to the company's needs to maximise technological use and function in providing data and information to top management and the rest of the business, as part of the strategy to facilitate business functions.

3.1.2 Customised Customer focus (Voice of the customer)

The second dimension is customed customer focus. Customer focus (CF) remains the main pillar of quality management. Goetsch and Davis (2014) compared customer focus to a driver's seat, which is the final arbiter of the journey as the customer determines the acceptable level of quality. Gaskin et al. (2010) termed the voice of a customer as a business phrase used to describe the process of eliciting customer requirements. It helps to generate a comprehensive list of customer wants and requirements that are grouped hierarchically and ranked according to their relative relevance and importance, as well as the level of satisfaction. Efimova and Briš (2021) posited that innovative technologies are advantageous to quality management processes and customer satisfaction. This is mainly driven by the amount of customer data that these technologies are capable of providing for decision-making and competitive advantage. This results from creating a customised customer when efforts are made to establish an environment that prioritises streamlined efficiency and customisation. Using big data, robots, machine learning and artificial intelligence facilitates efficiency and the development of solutions to significantly enhance customer performance (Mtotywa, Seabi and Moitse, 2021). In addition to customised customers, 4IR technologies enhance customer-relationship management (CRM) and penalty-reward contrast analysis. Studies generally demonstrate that customer-relationship management has a substantial impact on customer satisfaction and that the two variables are positively related (Hassan et al., 2015; Santouridis and Veraki, 2017). This means that if a business makes its CRM as robust and trustworthy as possible, its customers will more likely be satisfied and remain loyal. This was supported by Cavaliere et al. (2021) who found a correlation between CRM technology implementation and customer satisfaction, with a higher customer satisfaction rate correlating with increased CRM technology implementation. This can be complemented with an effective penalty-reward-contrast analysis (PRCA) that can be used to uncover asymmetric influences of product/service qualities on total customer satisfaction (Albayrak and Caber, 2013).

3.1.3 Technology-driven employee involvement and empowerment

The third dimension is technology-driven employee involvement and empowerment (EE). Technologies can be used in Quality 4.0 to improve employees' baseline skills and to increase their skills scale-up. Javaid et al. (2021) argued that social media, artificial intelligence, machine learning and virtual reality, among others, can be used to help with training and capacity building in the firm. Antony et al. (2022) highlighted that implementing Quality 4.0 would necessitate continual training and retraining of staff to pose a social problem. Furthermore, the societal consequences of Quality 4.0 will transform society into a knowledge-based society so that as repetitive operations are automated, a higher level of expertise will be required of quality specialists. In addition, Quality 4.0 will increase skills, including data science, programming, configuring and managing modern systems. Creativity, conflict resolution and emotional intelligence will be needed in the digital age.

3.1.4 Process and systems integration and management

The fourth dimension is the process and systems integration and management (PS). The TQM places a premium on process quality (Nguyeni and Nagase, 2019) as there is a cohesive link between the quality of the product or service, the quality of the process and the dimensional aspect of processes leading to an effective quality outcome for customer satisfaction. The quality management system is made up of interconnected procedures and an understanding of how this system produces outcomes allows an organisation to optimise the system and its performance. Sadikoglu and Olcay (2014) emphasised the importance of process management as it ensures activities through a collection of strategies, including preventive and proactive approaches. The technologies from the 4IR, especially enabling technologies such as the internet of things (IoT), cloud computing, integrated systems and virtual reality (VR), big data and blockchain (Carvalho et al., 2021) that enhance the quality of process and systems integration and management to help ensures that there is transparency and self-learning that optimise efficiency and performance. This also allows for early prediction of errors and less downtime by predicting early maintenance.

3.1.5 Knowledge for decision-making and future prediction

The fifth dimension is the knowledge for decision-making and future prediction (KP). Effective knowledge has long been at the forefront of planning and decision-making. It helps to minimise uncertainty which can create difficulties in businesses, with individuals and organisations attempting to minimise risks and maximise benefits (Petropoulos et al., 2022). Numerous business applications necessitate a variety of techniques to address real-world issues. This has become more critical with the increasing environmental turbulence that is experienced in the operating environment. Chatterjee and Chaudhuri (2021) highlighted such turbulence, which includes market turbulence, competitive intensity, technological turbulence and pandemic turbulence.

Fundin et al. (2020) reported that stability in change forms a component of the Quality 2030 agenda. This stability in change symbol emphasises the need to develop knowledge of the dynamics between stability and change through new knowledge that could lead to improvements in frameworks and management models to, in turn, lead and govern through rapid change. It may also boost the ability to drive both change and stability, both seen as possible synergistic allies. Honarpour, Jusoh and Nor (2012) posited that TQM practices improve knowledge creation and transformation. Utilising information effectively in quality management boosts the success of quality improvement operations. Within the scope of quality management, organisational processes should be addressed that ensure synergistic coupling of data and information tracking to innovative to capacity development of the workforce. Such knowledge transfer guarantees ongoing augmentation of complete quality management (Long et al., 2016).

3.1.6 Root cause analysis of operations disturbances and sustainable solution

The sixth dimension involves root cause analysis of operational disturbances and sustainable solutions (RC). Root cause analysis (RCA) is a very successful methodology for product design teams and production managers to engage in creative solutions that leverage instruments of the 4IR – Industry 4.0. This problem-solving method, launched as part of a bigger continuous improvement initiative, also includes the exploitation of digital applications and smart devices to communicate data across the firm in real-time (Vo, Kongar and Suárez-Barraza, 2020). While RCA is an excellent technique for determining the remote and immediate causes of events, it is ineffective in establishing effective preventative measures (Martin-Delgado et al., 2020). As such, it is important to move beyond RCA, and focus on the approach as provided by Lean Six Sigma, Theory of Constraints and Lean methodologies., which emphasise sustainable solutions. This solution can be tested with design of experiment (DOE) and simulation so as to obtain feasible solutions that satisfy all constraints and optimise yields and best value (Taha, 2017). Technology driven route cause analysis in operations disturbances using technologies such as the IoT focus on the data these devices collect, analyse, review and automate rather than on the cutting-edge, smart devices themselves (Guan et al., 2022). This knowledge, problem solving and root cause analysis can be handled more appropriately based on the acquired data. Managers can encourage staff to utilise these insights for good decision-making. Technology can also remove duplicate or tedious processes, thus streamlining the data necessary to conduct root cause analysis of operations disturbances, and in the process increasing the efficiency of a business.

3.1.7 Operational environment benchmarking

The last dimension is operational environment benchmarking (OB). Benchmarking is a quality management tool (Milosevic et al., 2013) that is part of breakthrough improvement involving discontinuous rather than gradual change. Operational environmental benchmarking includes competitive benchmarking of processes and products or service performance of competitors, process benchmarking of key work processes and strategic benchmarking, both strategies aimed at providing competitive advantage (Evans, 2017). Büyüközkan and Maire (1998) and Bhutta and Huq (1999) argued that benchmarking is a never-ending process of discovery and learning that finds and assesses the best practices and performance, so that it should be integrated into an organisation’s current activities to boost effectiveness, efficiency and flexibility. Because benchmarking is a continuous activity, this approach is aligned with Deming’s Plan-Do-Check-Act (PDCA) cycle (Moriarty and Smallman, 2009; Kailong, 2019). The defining characteristic of benchmarking is it’s incorporation into a comprehensive and inclusive policy for continual quality improvement (CQI). Conditions for successful benchmarking centre primarily on process planning, relevant indicator monitoring, staff participation and inter-organisational visits (Ettorchi-Tardy, Levif and Michel, 2012). Benchmarking may help improve quality and other interventions (Willmington et al., 2022).

3.2 Quality 4.0 Index Scale

As indicated in Figure 1, each of the seven dimensions has four items and so the developed Quality 4.0 maturity index is comprised of 28 items that together focus on understanding Quality 4.0 maturity within a business to improve its efficiency and performance.

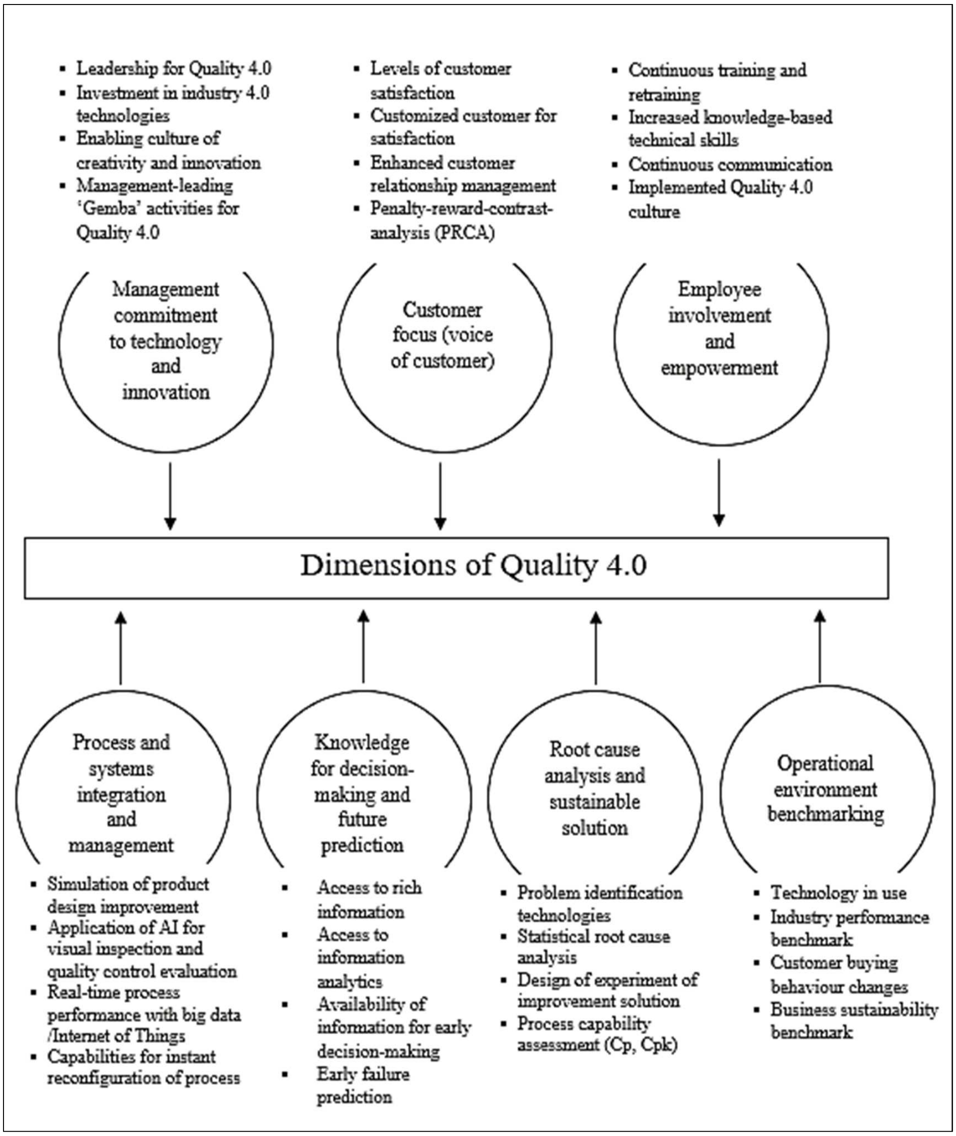

Figure 1 – Dimensions of Quality 4.0

3.3 Assessment of the Maturity Index

Assessment of the maturity index for each of the 28 items is evaluated using a 5-point scale from Level 1 to Level 5. Level 1 assesses the awareness of the business concerning quality management and the use of technology in quality management. Level 2 involves the initial or ad hoc use of technology for quality management. Level 3 is achieved when the business has established and is focused on improving critical business operations. Level 4 is achieved when there is confirmed efficiency and operational performance from an established process and effectively measured efficiency. In Level 5, the business shows a level of maturity and realises a return on investment (ROI) from the use of Quality 4.0 through cost saving, market share growth, safety improvements, profitability, improved customer satisfaction, customer-repurchase or competitive advantage. The investment can be quantified with established financial instruments such as net present value (NPV), internal rate of return (IRR) or payback. These index assess each of the seven dimensions (MC, CF, EE, PS, KP, RC, OB) developed in this Quality 4.0 model (Appendix, Table A1).

3.4 Business Maturity Level

3.4.1 Fit for covariation

It is crucial to verify the comparability of Quality 4.0 dimension measures, since respondents from two different settings may view these dimensions differently (Malhotra et al., 2013). This may be developed using the concept of fit as covariation as described by Venkatraman (1989) that is based on the view that underlying theoretical variables are related and require consistent attention across all of them. Venkatraman (1989) further argued that in this perspective, there is a requirement for high precision in the patterns of logical consistency among the dimensions. The covariation can be modelled with exploratory and confirmatory factor analysis (EFA).

Such EFA is based on the model of common factors with variables expressed as a function of common factors, unique factors and measurement errors (Watkins, 2018; Mtotywa, 2019). Each distinct factor affects a single manifest variable and cannot account for correlations between variables. The factor structure involves sphericity and KMO measurement to determine the feasibility of conducting factor analysis (Dziuban and Shirkey, 1974; Asadollahfardi et al., 2015).

The Kaiser, Meyer, Olkin (KMO) measure of sampling adequacy (MSA) quantifies the degree to which each variable in a set is accurately predicted by the other variables (Kaiser, 1974). The Kaiser-Meyer-Olkin (KMO) statistic ranges from 0 to 1 where a value of 0 indicates that the sum of partial correlations is significantly larger than the sum of correlations, implying that factor analysis is likely ineffective. A KMO value near unity indicates that the sum of partial correlations is small compared to the sum of correlations, suggesting that factor analysis should produce distinct and reliable factors. Performing factor analysis requires specifying the number of retained or extracted components (or latent variables). This choice is frequently motivated or justified by statistical indices and procedures that aim to determine the optimal number of factors. The number of retained factors is based on an Eigen value ($\psi \geq 1.0$) and/or Scree plot.

The Bartlett's Sphericity Test determines whether a matrix (of correlations) deviates significantly from the identity matrix. The test indicates the likelihood that the correlation matrix contains significant correlations between at least some of the variables in a dataset, a condition necessary for factor analysis to work. In other words, before beginning factor analysis, one must determine the significance of Bartlett's Test of Sphericity.

The confirmatory factors analysis can then be used to validate the constructs with structural equation modelling (SEM), either covariant (SEM-CB) or partial least square (PLS-SEM). The convergent validity is evaluated with average variance extracted (AVE) using equation 1:

$$AVE = \frac{\sum \lambda^2}{n} \tag{1}$$

where λ is the factor loading while n is the indicator in the factor. Using equation 2, discriminant validity (DV) can then be determined using the square-root value of AVE to compare with inter-construct correlation values where the square root of AVE should be higher than inter-construct correlation values:

$$DV = \sqrt{AVE} \tag{2}$$

DV is the discriminant value and there is discriminant validity if:

$$AVE > MSV \tag{3}$$

$$AVE > ASV \tag{4}$$

where MSV is the Maximum Shared Variance, while ASV is the Average Squared Shared Variance.

In PLS-SEM, the Heterotrait-Monotrait criterion ($HTMT$) is used to determine the discriminant (Hair et al., 2018):

$$HTMT_{ij} = \frac{W}{\sqrt{R \ x \ Q}} \tag{5}$$

where W is the average heterotrait-heteromethod correlations, which is the average of all pairwise correlations between items of the first construct and the second construct. R is the average monotrait-heteromethod correlations, which are means of all pairwise correlations between items of the first construct. Q is the average monotrait-heteromethod correlation which are all pairwise correlation between items of the second construct. The reliability is determined using composite reliability:

$$CR = \frac{(\sum \lambda)^2}{(\sum \lambda)^2 + (\sum \varepsilon)} \tag{6}$$

where ε = 1- λ. The development of the valid and reliable Quality 4.0 constructs confirms results that indicate support for measure equivalence, which permits appropriate comparisons and interpretation of the results when characterising the quality of a maturity model (Byrne, 2004; Asdecker and Felch, 2018).

3.4.2 Composite score for the level of Quality 4.0 maturity

The next step is to conduct a Quality 4.0 business maturity level. The relative score is then translated into a maturity stage, with the five steps describing a route to maturity, *i.e.,* excellence in leveraging Quality 4.0 for efficiency and performance in the business. The MID is the quality maturity index score of the individual dimensions (*MC, CF, EE, PS, KP, RC, OB)* that were indicated in Figure 1, in the operational process, *j* in the organisation:

$$MID_j = \frac{\sum_{i=1}^{4} QI_{ij}}{4} \tag{7}$$

where QI_1, QI_2, QI_3,QI_4 are items used for assessing Quality 4.0 maturity. For the total composite score for all items, CC:

$$CC_j = \frac{MC_{ij} + CF_{ij} + EE_{ij} + PS_{ij} + KP_{ij} + RC_{ij} + OB_{ij}}{7} \tag{8}$$

With the the overall quality maturity index score for the process, QMI_j:

$$QMI_j = \frac{CC_j}{5} X100\% \tag{9}$$

AWR (≤ 0.20), AWR – ADH (0.20 ≤ QMI ≤ 0.40), EFP (0.40 ≤ QMI ≤ 0.60), EFP-IMP (0.60 ≤ QMI ≤ 0.80), ROV (≥ 0.80). Zero to 1 is 0% to 100%.

3.5 Operationalisation of the Quality 4.0 Maturity Index

The operationalisation of the Quality 4.0 maturity index would work in the following manner using a fictitious set of data as indicated in Table 1.

This index is applicable in processes, a business unit or organisation and group of experts or people with in-depth knowledge of an area of investigation. These individuals must be selected carefully and should be limited to subject matter experts, process owners, internal or external consultants with relevant expertise and senior management. The fit for covariance will mainly be applicable in the analysis group of experts or people with in-depth knowledge of process or organisation, as there should be sufficient data for accumulation.

In this theoretical example, the measure will be the mean scores ($\check{Q}$). The MID is computed based on equation 7 and on this fictitious data and the overall MID_j = 25.75. Based on equation 8, CC_j = 3.679 and using equation 9, QMI_j = 73.57%. The maturity index based on the guidelines provided is EFP-IMP (60.0% ≤ QMI ≤ 80.0%). In this scheme, a high score closes to 1 (100%) indicates higher maturity in leveraging the advantages of Quality 4.0 for improved efficiency and organisational performance, while a lower score shows the opposite potential.

Table 1 – A Numerical Illustration of Operationalisation of the Maturity Index in Implementing Quality 4.0 in the Business

Maturity index dimension	Measured Score (QI_1,)*	Measured Score (QI_2)*	Measured Score (QI_3)*	Measured Score (QI_4)*	Number of items per dimension	MID
MID_1	1	5	4	3	4	3.25
MID_2	4	5	3	3	4	3.75
MID_3	5	3	2	5	4	3.75
MID_4	2	5	2	3	4	3.00
MID_5	5	5	3	5	4	4.50
MID_6	4	5	3	4	4	4.00
MID_7	5	2	5	2	4	3.50
						25.75
CC_j						3.679
QMI_j						73.57%

Notes: * - fictitious data.

4 CONCLUSION

Quality 4.0 is regarded as an expanded approach to quality management in which new technologies are combined with established quality techniques (QC, QA, TQM) in order to broaden the scope of quality management and to improve quality operations (Sader, Husti and Daroczi, 2022). Developing a Quality 4.0 maturity index for improved operational efficiency and performance is critical for businesses as they are faced with adapting to environmental turbulence from changes in customer behaviour and preferences as well as recovery from the COVID-19 pandemic, which has hugely disrupted industries (Nicola et al., 2020).

The Quality 4.0 maturity index was constructed in the study based on seven different characteristics of ongoing quality improvement. These include a management commitment to technology and innovation-driven operations, a customer focus that enhances the voice of the customer, employee involvement and empowerment, integration and management of processes and systems, root cause analysis of operational disturbances and sustainable solutions, knowledge for decision-making and future prediction as well as benchmarking of the operating environment.

In addition, the level of maturity of various aspects of the company is evaluated using a scale with five levels, beginning with the stage of awareness (Level 1) and progressing all the way up to an optimised process with evidence of return on investment (Level 5). Whether or not the index is helpful is determined through the use of fit as covariation and a composite score for the level of Quality 4.0 maturity.

4.1 Theoretical Implications of the Study

Quality 4.0 analytical strategies add to the body of knowledge to enhance total quality management already enhanced by technologies associated with the fourth industrial revolution. As Efimova and Briš (2021) highlighted that Quality 4.0 is still in its infancy and no standard has been established, use of such strategies can help to improve the business and industry base surrounding Quality 4.0,. Thus, this study has also contributed to the quality 2030 agenda which focuses on quality management of the future, in particular the “stability in change” which relates to the idea that organisations require not only continuity or stability, but also change, including disruptive change involving technologies (Fundin et al., 2020).

4.2 Practical Implications for Management

Management in businesses should make an effort to create an enabling environment that will allow for effective implementation of Quality 4.0. Quality 4.0 provides numerous benefits to quality management, including increased speed and transparency, increased adaptability to new situations and continual improvement across businesses plus increased awareness, skills and intelligence. It helps with industrial transformation and has a direct effect on customer service and satisfaction, or its product or service customisation (Milunovic Koprivica et al., 2019). Adopting a novel quality paradigm necessitates changes at every level of the business, along with societal and technological changes that are required to adapt to Quality 4.0 – thus, important adjustments to management models and systems are also required (Dias, Carvalho and Sampaio, 2021). The study also aimed at practically benefiting a business by focussing on improved business capacity and capability to mitigate the environmental turbulence associated with pandemics, geopolitical instabilities and other turbulence.

4.3 Strength and Limitations of the Research

The strenght of the research model is dependent on the depth of theory on TQM and the continued development of Quality 4.0, factors that are synthesised and presented in this paper. The development follows an approach towards effective development of a maturity index (Venkatraman, 1989; Schumacher, Erol and Sihn, 2016; Asdecker and Felch, 2018). Despite this, the research is theoretical and has not been validated by empirical evidence. This means that the maturity index model should be optimised following the incorporation of empirical data, a limitation of the research.

4.4 Direction for Future Research

Quality 4.0 is still in its infancy and necessary improvements to it will demand resources. Nonetheless, the benefits of technologies in quality management could offer industrial businesses a competitive advantage (Efimova and Briš, 2021). It is suggested that a validation study be done using the methodology and principles outlined in the article. This can be done across different business value chains. Although the model is potentially applicable across all business sections and operations where it is used, the greater the comprehensive nature of its testing should provide increased validation for the model.

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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

Table A1 – Quality 4.0 Assessment of Maturity Index

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Dimensions: Management commitment to technology and innovation					
Leadership for quality 4.0	Leaders not aware of Quality 4.0	*Ad hoc* activities by leaders on Quality 4.0	Leaders have vision and implemented Quality 4.0 in the firm	Quality 4.0 implemented across operations with benefits driven by leaders	Firm quantifying return on investment from Quality 4.0
Investment in industry 4.0 technologies	No firm investment in 4IR technologies	*Ad hoc* investment in 4IR technologies	Firm investment in 4IR technologies part of strategy linked resource allocation	Optimised investment for all critical and interlinked 4IR technologies for operations	Positive NPV/IRR/ payback for optimised investment on 4IR technologies for operations
Enabling culture of creativity and innovation	No technology-driven creativity and innovation culture	*Ad hoc* technology-driven creativity and innovation culture	Established technology-driven creativity and innovation culture	Organisation-wide established and managed technology-driven creativity and innovation culture	Improved efficiencies and performance from optimally managed technology-driven creativity and innovation culture
Management leading 'Gemba' activities for Quality 4.0	No ‘Gemba’ activity on Quality 4.0	Initial ‘Gemba’ activity on Quality 4.0	Established focused ‘Gemba’ activity on Quality 4.0	Improved and managed process ‘Gemba’ activity on Quality 4.0	Evidence of return on investment ‘Gemba’ activity on Quality 4.0
Dimensions: Customer focus (voice of customer)					
Levels of customer satisfaction	Customer satisfaction not measured	*Ad hoc* measurement of customer satisfaction	Established Customer satisfaction	Technology-driven continuous customer satisfaction assessment	Re-purchase and loyalty from customer satisfaction
Customised customer for satisfaction	No customised customer activities in place	*Ad hoc* customised customer activities in place	Established customised customer activities	Managed customised customer activities in place	ROI from customised customer activities

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Enhanced customer relationship management	No customer relationship management in use	*Ad hoc* use of customer relationship management system	Established technology-driven customer relationship management	Continuous technology-driven customer relationship management	ROI from customer relationship management
Penalty-reward contrast analysis (PRCA)	No awareness of PRCA	Awareness and initial use of PRCA	Established and focused use of PRCA	Improved and managed process of PRCA	Firm quantifying return on investment from PRCA
Dimensions: Employee involvement and empowerment					
Continuous training and retraining	No technology-based training	*Ad hoc* technology-based training	Established technology-based training	Advanced technology-based training	ROI on technology-based training
Increase knowledge-based technical skills	No technology-based technical skills	Low technology-based technical skills	Established technology based technical skills	High technology-based technical skills	ROI from high technology-based technical skills
Continuous communication	Non-existent communication in firm	*Ad hoc* technology-driven communication	Established technology-driven communication	Technology-driven internal and external communication	Financial or non-financial ROI on communication
Quality 4.0 firm culture	No total quality culture in firm	*Ad hoc* implementation of total quality culture in the firm	Established focused culture of quality 4.0	Organisation-wide established quality 4.0 culture	Improved efficiencies and performance from Quality 4.0 culture
Dimensions: Process and systems integration and management					
Simulation of product design improvement	No Simulation in use in firm	*Ad hoc* use of simulation technology	Established simulation technology in use	Operations wide simulation in use in firm	ROI from simulation in use in firm
Application of AI for visual inspection and / quality control	No AI or other VR technology in use for inspection/ control	*Ad hoc* technology use in inspection/ control	Established AI or other VR technology in use for inspection / control	Operations wide AI or other VR technology in use for inspection / control	ROI from AI or other VR technology in use for inspection / control

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Real-time process performance monitoring with big data / IoT	No real time process performance monitoring	*Ad hoc* process performance monitoring	Technology driven real time process performance monitoring	Operations wide real time process performance monitoring	ROI from real time process performance monitoring
Capabilities of instant reconfiguration of process	No capabilities of instant reconfiguration of process	Initial capabilities of instant reconfiguration of process	Established capabilities of instant reconfiguration of process	Operations wide capabilities for instant reconfiguration of process	ROI on capabilities and outcomes of instant reconfiguration of process
Dimensions: Knowledge for decision-making and future prediction					
Access to rich information	Operations information not available	*Ad hoc* availability of operations information	Established technology-driven operations information	Operations wide technology-driven information availability	ROI from Operations wide technology-driven information availability
Access to information analytics	No access to information analytics	*Ad hoc* access to information analytics	Established access to information analytics	Operations wide technology-driven access to information analytics	ROI from Operations wide technology-driven access to information analytics
Availability of information for early decision-making	No available information for early decision-making	*Ad hoc* availability of information for early decision-making	Established available information for early decision-making	Operations wide technology-driven information for early decision-making	ROI from Operations wide technology-driven information for early decision-making
Early failure prediction	No early failure prediction	*Ad hoc* early failure prediction	Established early failure prediction technology in use	Operations wide technology-driven early failure prediction	ROI on Operations wide technology-driven early failure prediction

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Dimensions: Root cause analysis and sustainable solution					
Problem identification technologies	No problem identification technology in use	Initial or *Ad hoc* use problem identification technology	Established problem identification technology in use	Real-time/on-line problem identification technology in operations	Quantified return on investment from Real-time/on-line problem identification technology in operations
Statistical root-cause analysis	No route-cause analysis process	*Ad hoc* route cause analysis process	Established technology-driven root cause analysis process	Operations interconnected technology-driven root cause analysis	Financial and non-financial return on investment from root cause analysis
DOE for improvement solution	DOE not in use for improvement solution	DOE in use for improvement solution at ad hoc basis	Established DOE in use for improvement solutions	DOE improves design or processing of product or services	DOE result in costs saving/eliminating waste / increase profitability/ customer satisfaction
Process capability assessment	Process capabilities not assessed	*Ad hoc* process capabilities assessed	Established procedure and implementation of capabilities assessment	Process capabilities assessment leveraged for improved design or processing of product or services	Process capabilities saving costs/eliminating waste/increase in profitability/customer satisfaction
Dimensions: Operational environment benchmarking					
Technology in use	No Technology in use	*Ad hoc* technology use in operation	Established use of technology in operation	Improved and managed process technology across operations	Financial or non-financial returns from technology across operations

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Industry performance benchmark	No Industry performance benchmark	*Ad hoc* industry performance benchmark	Technology-based industry performance benchmark implemented	Comprehensive firm strategy aligned to industry performance benchmark	Return on investment on performance benchmark with improved competitive advantage/ profitability
Customers buying behaviour changes	No monitoring of customer buying behaviour changes	*Ad hoc* monitoring of customer buying behaviour changes	Technology monitoring of customer buying behaviour changes	Effectively managed process of monitoring customer buying behaviour changes	Return on investment (cost saving or market share growth) from strategy culminating from monitoring customer buying behaviour changes
Business sustainability benchmark	No sustainability plan	*Ad hoc* sustainability activities, with aid of technology	Technology-driven sustainability plan in place and implemented	Technology-driven continuous sustainability benchmark	Firm leveraging technology-driven sustainability for competitive advantage and future growth

The Moderating Role of IT Development on the Relationship between Internal Control and the Quality Performance of Higher Education Institutions

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ABSTRACT

Purpose: This study examines the extent to which IT development for internal control purposes has been implemented. Also, it investigates the moderating effect of IT development on the relationship between internal control implementation and Higher Education Institution (HEI) quality performance.

Methodology/Approach: This research employed a survey method by distributing questionnaires to HEIs in all 34 provinces of Indonesia. As a result, 191 HEIs participated in this study. A Partial Least Squares (PLS) with the second-order analysis was utilised to test the relationship among the variables.

Findings: The results revealed that the IT development for internal control purposes was generally moderate. Additionally, IT development was positively associated with internal control implementation and strengthened the relationship between internal control and HEI quality performance.

Research Limitation/Implication: This study was based solely on a weak survey study regarding depth and breadth of exploration. Additionally, it did not cross-validated by re-testing the proposed model with secondary data.

Originality/Value of paper: This study adds to the body of knowledge on the moderating role of IT development. Also, the results of this research can be a meaningful input for HEI management since many consider internal control carried out manually to be sufficient without the role of IT. In fact, IT development can strengthen (be a moderator) the positive relationship between internal control and HEI quality performance.

Category: Research paper

Keywords: higher education institution; internal control; information technology; quality performance

1 INTRODUCTION

Information technology (IT) developments in not-for-profit organisations (NFPOs), such as government, higher education institution (HEI), hospital and others, can be said to lag the corporate sector. However, NFPOs have also started concentrating on more advanced IT development for governance and performance improvement purposes. For instance, by 2018, the Indonesian government had recommended that all HEIs advance IT to support all management and governance practices, including internal control (IC) implementation (Kemenristekditi, 2018). This recommendation is also a follow-up to the issuance of the 2009 regulation for implementing internal control to mitigate fraud in HEI and promote better HEI quality performance (Sofyani, Abu Hasan and Saleh, 2022). As much literature claims, strengthening IT's aspects can maximise the role of internal control within the organisation (Rubino, Vitolla and Garzoni, 2017; COSO, 2013). However, certain IT investments in organisations do not always guarantee additional value-added if the readiness of human resources and organisational environment is not considered (Reich, 2021). So far, empirical research that answers the basic question of the extent to which HEI has developed IT for internal control purposes and whether it has promoted any value toward HEI is still lacking.

In addition, research exploring other roles from the IT aspect apart from being a determinant of performance and good governance, as moderator, for instance, is still rare, especially in developing country settings, such as Indonesia. Hence, Rubino, Vitolla and Garzoni (2017) suggested exploring this issue further to get more empirical evidence about IT development for internal control, especially related to its organisational contribution. Ali, Green and Robb (2015) also claimed that IT can play a role in an organisation's strategy to pursue competitive advantage when it is positioned not only as a tool yet integrated with the organisation's strategy. Likewise, Asiaei et al. (2021) contended that, as resource orchestration theory suggested, mobilised resources integrated into a robust system could create better alignment, coordination and direction for specific organisational achievement. Drawing on that insight, a better HEI quality performance could be achieved if the two internal HEI resources, IT and internal control, could be mobilised in harmony. However, this premise lacks empirical evidence.

To address highlighted gaps above, this study explicitly examines the extent to which IT development for internal control purposes has been implemented in the HEI sector in developing countries study setting by taking a sample of Indonesia.

2 METHODOLOGY

Explicitly, this study investigates the role of IT development as a determinant of internal control and as a moderator of the relationship between internal control and HEI quality performance. By doing so, this study provides fresh insights regarding the empirical evidence on the role of IT development for internal control purposes in the context of non-enterprise organisations, namely the HEI sector that, according to Chalmers, Hay and Khlif (2019), still receive minimal attention by academics. The findings of this study are also useful as input for practitioners and the development of related literature.

2.1 Research Model

IT development is considered able to support governance policies, including internal control (Queiroz et al., 2018). In this paper, the IT_IC term is used to express IT development for internal control purposes. Although IT_IC is part of the internal control systems, several studies have tested the relationship between the two concepts. Grant, Miller and Alali (2008) found that companies with more IT_IC deficiencies reported more accounting errors and internal control weaknesses and paid more audit fees. It aligns with Mazza and Azzali (2018), who found that companies with good IT_IC tended to be low risk, and as a result, the audit fee would be small. Moreover, Abbaszadeh, Salehi and Faiz (2019) revealed that alteration of data collection methods from traditional to modern (IT-based) had enhanced the internal control effectiveness in Iranian state agencies.

In addition, an optimal IT role in improving performance can be done by putting it as a strategic tool. To do so, IT must be synchronised with other policies (Ali, Green and Robb, 2015; Sofyani, Riyadh and Fahlevi, 2020). Drawing from this insight, the IT and internal control will be more powerful in encouraging the organisation to achieve its competitive advantage if these resources are run in harmony and well synchronised. This condition corroborates the premise of the resource orchestration perspective (Sirmon et al., 2011). Several studies have examined IT's role as a moderating variable influencing organisational performance using the resource orchestration theory's perspective. Zhou et al. (2017) suggested that integrating resource management with modern IT might assist firms in effectively identifying and accumulating their unique resources, developing their capabilities and creating values. Meanwhile, Saeidi et al. (2019) uncovered that IT strategy and IT structure directly affected the competitive advantage and had a moderating effect on the enterprise risk management-competitive advantage relationship.

Based on the theoretical framework and forgoing discussions, the research model was formulated as presented in Figure 1, and the hypotheses were developed as follows:

H_1: IT_IC development is positively associated with internal control implementation.

H_2: IT_IC development strengthens the relationship between internal control implementation and HEI quality performance.

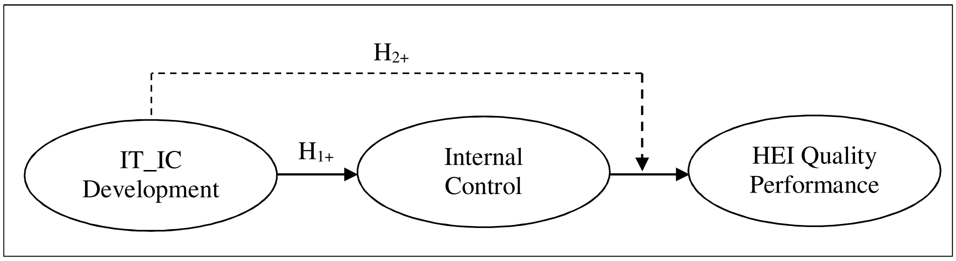

Figure 1 – Research Model

This study involved all Indonesian HEIs as a population. The samples were determined by a non-probability approach, namely purposive sampling. HEIs were chosen as samples if they had implemented internal control and developed IT to support that policy (Sekaran and Bougie, 2019). In selecting respondents, judgment sampling was employed. In addition, the respondents should be in the best position to provide the required information (Sekaran and Bougie, 2019). Hence, in this study, the respondents involved were management members of internal control and internal quality assurance units in HEI. As this study utilised a non-probability sampling technique, Memon et al. (2020) argued that power analysis is recommended to determine sample size. Based on the power calculation, the minimum sample size of this study was 77 HEIs.

The questionnaire used in this research was adapted and developed from previous internal control and accounting information system studies. Besides, the Indonesian Government Regulations regarding the internal control for Indonesian HEI were also referred to. Explicitly, the COSO integrated framework (2013) was adapted as the primary reference in developing internal control measurement since the Indonesian government has officially adopted it. In detail, it consists of five components: control environment, risk assessment, control activities, information & communication, and monitoring activities (Figure 2). Furthermore, in developing IT_IC measurement, Rubino, Vitolla and Garzoni (2017) were adapted as the main reference since it was formulated following the internal control framework developed by COSO (2013). Specifically, IT_IC includes three dimensions: IT organisational controls, IT process controls, and IT soft variables controls. Additionally, due to the research context, an accreditation assessment instrument for the Indonesian HEI of 2019 was employed to measure HEI quality performance.

In this research, two sets of questionnaires were prepared. Ques-1 containing questions related to IT_IC and internal control variables was given to internal control unit management members. Meanwhile, Ques-2 containing quality performance was given to management members from the internal quality assurance unit. This separation of data sources considered the suitability of the parties who filled in the questionnaire where they should be the ones who expertise the points being asked (Sekaran and Bougie, 2019). In addition, separating data sources is also useful to avoid Common Method Bias (Chang, Witteloostuijn and Eden, 2020). All variables in the questionnaire were scaled using a Likert of 0 to 5, where 0 = Not Visible/Not Implemented and 5 = Strongly Agree. Following Lewis, Templeton and Byrd (2005), some experts were asked to validate the questionnaire before utilising it in a field. The expert consultation results were followed up with questionnaire improvement.

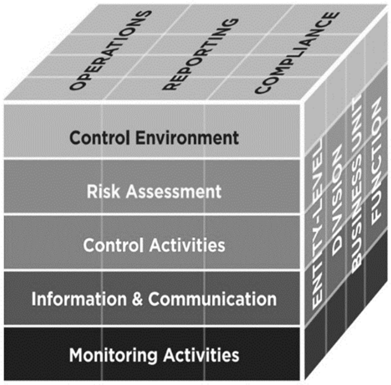

Figure 2 – COSO Integrated Framework of 2013 (COSO, 2019, p.5)

Then, data analysis was conducted to provide descriptive statistics and hypothesis testing results. To do so, Microsoft Excel and the variant-based Partial Least Square-Structural Equation Modelling (PLS-SEM) approach were employed. Specifically, this study used a higher-order construct analysis because the internal control and IT_IC variables were constructed by several dimensions with formative types (Becker, Klein and Wetzels, 2012). Additionally, a two-stage approach was adopted for testing the moderating effect because it was considered the most suitable for formative constructs compared to other approaches (Memon et al., 2019).

3 RESULTS

Details of the current study response rate are presented in Table 1. As highlighted earlier, the minimum sample size for this study should be 77 HEIs. Then, since this study could get 191 HEIs as the final sample size, it had reached the required minimum sample size suggested.

Due to the self-reported nature of the survey research data, there was a potential for common method variance (CMV) (Podsakoff et al., 2003). One of the common methods used to detect this issue is Harman's single factor test (Tehseen, Ramayah and Sajilan, 2017). The results showed that a total variance explained 78.62%, and the first factor only explained 29.57% or less than 50%. These results confirm that common method bias was not a serious problem in this research (Podsakoff et al., 2003).

Table 1 – Survey Response Rate

Detail	**Internal Control and IT Controls Questionnaire Responses (Ques-1)**		**HEI Quality Performance Responses (Ques-2)**	
	Frequency	%	Frequency	%
Sent	628	100.00	628	100.00
Received	271	43.15	233	37.1
Un-appropriate respondent	15	4.30	25	3.98
Extreme answer	5	0.80	1	0.16
Did not fill in Ques-1	-	-	15	2.39
Did not fill in Ques-2	60	9.55	-	-
HEI that completed both questionnaires	191	30.41	191	30.41
Usable questionnaire for hypothesis testing (the percentage based on ideal sample size, i.e., 77)	191	53.80	191	53.80

Furthermore, Table 2 presents the results of descriptive statistical analysis. In this paper, the scoring of policy implementation was divided into three levels following the Likert scale: 0 to 2 = low; 2.1 to 3.9 = moderate; 4 or more = high. It was found that, in general, the internal control and IT_IC dimensions implementation was at a moderate level. In comparison, the quality performance of HEI was also at a moderate level, not yet high. It indicates that, in general, these variables still need to be improved. Additionally, some dimensions even had a minimum score of 0.00. It denotes that the dimensions in question have not yet been implemented by related HEIs.

Table 2 – Descriptive Statistics

	COEV	RISKAS	COACT	INCOM	MON	IT_OC	IT_PC	IT_SVC	QUAL
Min	1.59	0.00	1.30	0.00	0.40	0.00	0.00	0.00	1.03
Max	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	4.93
Mean	3.92	3.78	4.09	4.09	3.85	3.78	3.85	3.53	3.30
SD	0.69	0.87	0.76	0.73	0.87	0.92	0.90	0.98	0.67

Notes: COEV: Control Environment; RISKAS: Risk Assessment; COACT: Control Activities; INCOM: Information and Communication; MON: Monitoring; IT_OC: Information Technology Organisational Controls; IT_PC: Information Technology Process Controls; IT_SVC: Information Technology Soft Variables Controls; QUAL: Quality Performance.

As this study focused on IT_IC development, only the findings on the implementation of this variable were elaborated in detail.

3.1 IT Organisational Controls

In general, according to Table 3, the IT organisational controls implementation was still at a moderate level. A "Not Visible" answer was also found in each indicator, meaning that the policy in question was not implemented yet. In other words, the implementation of the indicators was still done manually. In addition, some respondents answered "Disagree" and "Strongly Disagree", indicating that implementing IT organisational controls indicators has not been going well. However, those who answered these scales were still low, under 10% of the total respondents.

Table 3 – Mean and Frequency Scores of IT Organisational Controls

Code	Indicator	Mean Score	Not Visible		Strongly Disagree + Disagree		Agree + Strongly Agree	
IT_OC1	IT use to oversee authority in an assignment	3.73	3	1.20%	21	8.37%	167	66.53%
IT_OC2	IT use to oversee the implementation of an assignment's responsibilities	3.79	3	1.20%	19	7.57%	171	68.13%
IT_OC3	IT use to manage formal reporting lines (activity and program reports)	3.80	4	1.59%	17	6.77%	169	67.33%
IT_OC4	IT use to oversee the implementation of tasks	3.79	5	1.99%	16	6.37%	175	69.72%
IT_OC5	IT use to monitor individual employee performance	3.76	6	2.39%	18	7.17%	172	68.53%
IT_OC6	IT use to organise adequate segregation of functions to prevent fraudulent collusion	3.73	5	1.99%	22	8.76%	174	69.32%
IT_OC7	IT use to regulate the implementation of all transactions in accordance with applicable SOPs/policies	3.84	7	2.79%	15	5.98%	182	72.51%

Notes: Respondents' answer on a scale of 3 was not included. IT_OC: Information Technology Organisational Controls.

3.2 IT Process Controls

Based on the mean and frequency analysis results shown in Table 4, this aspect was also not running optimally, seen from none of the mean indicator scores exceeding a scale of 4. However, this dimension was generally implemented at a moderate level because most of the mean scores were above 3.75, and most respondents answered “Agree” and “Strongly Agree”.

Table 4 – Mean and Frequency Scores of IT Process Controls

Code	**Indicator**	**Mean Score**	**Not Visible**		**Strongly Disagree + Disagree**		**Agree + Strongly Agree**	
IT_PC1	IT use to regulate the documentation of transactions in accordance with applicable SOPs/policies	3.91	5	1.99%	13	5.18%	193	76.89%
IT_PC2	IT use to regulate the recording of transactions in accordance with applicable SOPs/policies	3.92	5	1.99%	13	5.18%	196	78.09%
IT_PC3	IT use to regulate the authorisation/ratification of all transactions in accordance with the applicable SOP/policies	3.81	7	2.79%	15	5.98%	179	71.31%
IT_PC4	IT use to prepare information for reference decision making at all levels of management	3.87	6	2.39%	12	4.78%	189	75.30%
IT_PC5	IT use to limit accessibility to important information	3.78	6	2.39%	21	8.37%	175	69.72%
IT_PC6	IT use to report programs and activities	3.91	4	1.59%	16	6.37%	190	75.70%
IT_PC7	IT use to oversee the adequacy of financial resources for campus operations	3.82	4	1.59%	26	10.36%	175	69.72%
IT_PC8	IT use to oversee the use of campus financial resources	3.84	5	1.99%	23	9.16%	180	71.71%
IT_PC9	IT use to oversee the use of campus physical assets	3.76	4	1.59%	23	9.16%	172	68.53%

Code	Indicator	Mean Score	Not Visible		Strongly Disagree + Disagree		Agree + Strongly Agree	
IT_PC10	IT use to calculate employee incentives based on their performance	3.82	6	2.39%	24	9.56%	176	70.12%

Notes: Respondents' answer on a scale of 3 was not included. IT_PC: Information Technology Process Controls.

3.3 IT Soft Variables Controls

IT soft variables controls refers to maximising the role of IT to monitor the socialisation and implementation of the code of ethics formulated by the organisation. The results revealed that this dimension implementation was the lowest in the Indonesian HEIs context, with the mean scores ranging from 3.31 to 3.88, as displayed in Table 5.

Table 5 – Mean and Frequency Scores of IT Soft Variables Controls

Code	Indicator	Mean Score	Not Visible		Strongly Disagree + Disagree		Agree + Strongly Agree	
IT_SVC1	IT use to monitor the availability of information on campus code of ethics	3.46	10	3.98%	29	11.55%	140	55.78%
IT_SVC2	IT use to socialise the campus code of ethics periodically	3.48	8	3.19%	31	12.35%	145	57.77%
IT_SVC3	IT use to report violations of the campus code of ethics	3.31	8	3.19%	42	16.73%	123	49.00%
IT_SVC4	IT use to calculate the number of employees attendance (lecturers and employees) in training held by the campus	3.88	3	1.20%	25	9.96%	174	69.32%

Notes: Respondents' answer on a scale of 3 was not included. IT_SVC: Information Technology Soft Variables Controls.

3.4 Measurement Model

It should be noted that the constructs in this model consisted of two types, wherein internal control and IT_IC used formative constructs, while HEI quality performance employed a reflective type. Therefore, validity and reliability testing referred to different criteria (Hair et al., 2021). In the first test, some of the construct indicators' outer weight and loading values did not meet the rule of thumb. Hence, they were dropped. In the second test, it was found that the loadings test results showed that all loadings had been more than 0.5 (Table 6). It was also uncovered that the HEI quality performance construct had the AVE value that agreed with the rule of thumb required of 0.50 (Table 8). Therefore, the data met convergent validity (Hair et al., 2021).

Table 6 – Outer Loadings

Dimension	Indicator	Item	Loadings
Control Environment	COEV1	Our campus details the activities needed to complete tasks in each campus unit position (i.e., Dean, Head of Department, Head of Units and others.).	0.803
	COEV4	Our campus adjusts the organisational structure concerning environmental changes if necessary.	0.737
	COEV5	All our campus employees (lecturers and employees) have the competencies to carry out their duties/jobs.	0.643
	COEV6	The finance staff team responsible for preparing financial reports in all campus units has a background in accounting education.	0.533
	COEV10	People appointed as leaders at all levels of management have strong capabilities.	0.798
	COEV17	Top leaders at our campus are always careful in taking action/decisions.	0.793
Control Activities	COACT6	Campus physical asset control reviews are conducted periodically.	0.835
	COACT7	Information technology updates for control purposes are carried out periodically.	0.877
	COACT9	Academic activities get continuous supervision.	0.821
Information and Communication	INCOM1	Our campus management at all levels/units is supported by various communication features easily accessible for coordination (for example, chat, video conferencing and e-mail).	0.727
	INCOM5	Reviews of the implementation of internal control on campus are carried out by always involving competent external campus parties (assessors from HEI accreditation assessors, other HEIs' internal control forums or auditors from public accounting firms).	0.872
Monitoring	MON1	At our campus, the results of audits or reviews related to internal control are always followed up.	0.904
	MON2	At our campus, rapid procedures for identifying internal control weaknesses are available.	0.875
	MON3	Identified internal control weaknesses are always reported to the authorities on campus.	0.823

Dimension	**Indicator**	**Item**	**Loadings**
Risk Assessment	RISKAS1	Campus goals/targets are prepared by always considering possible risks.	0.848
	RISKAS3	On our campus, at every management level, the relevant risks are analysed first before a decision is taken/made.	0.889
	RISKAS4	Any potential fraud that can affect campus goals/targets is always identified to be mitigated.	0.888
IT Organisational Control	IT_OC3	IT use to regulate the authorisation/ratification of all transactions in accordance with the applicable SOP/policies	0.958
	IT_OC5	IT use to monitor individual employee performance	0.820
IT Process Control	IT_PC10	IT use to calculate employee incentives based on their performance	0.860
	IT_PC5	IT use to limit access to important information	0.605
	IT_PC6	IT use to report programs and activities	0.854
	IT_PC9	IT use to oversee the use of campus physical assets	0.842
IT Soft-Variable Control	IT_SVC3	IT use to report violations of the campus code of ethics	0.915
	IT_SVC4	IT use to calculate the number of employees attendance (lecturers and employees) in training held by the campus	0.783
Quality Performance	QUAL3	The number of study programs accredited by the International Accreditation Board recognised by the Indonesian Government	0.736
	QUAL4	Accreditation predicate of study program by Ministry of Education and Culture	0.706
	QUAL6	The number of new student selection	0.760
	QUAL7	The number of international students	0.709
	QUAL12	The outcome of the community service program	0.680
	QUAL13	Income generation performance	0.751
	QUAL14	Income level other than tuition fee	0.717
	QUAL24	The alumni work in multi-national companies or international institutions	0.660
	QUAL26	Number of patents or simple patents generated	0.672
	QUAL28	Number of appropriate technology, products, artwork, social engineering	0.688

Furthermore, the discriminant validity test results (Table 7) showed that the correlation between the HEI quality performance – the only reflective construct – was lower than the AVE root value itself (Fornell and Larcker, 1981). Thus, it signifies that discriminant validity has been established. Meanwhile, for formative constructs, this test was not required (coded FC) (Hair et al., 2021)

Table 7 – Discriminant Validity

	COACT	COEV	INCOM	IT_OC	IT_PC	IT_SVC	MON	QUAL	RISK
COACT	FC								
COEV	0.719	FC							
INCOM	0.654	0.644	FC						
IT_OC	0.605	0.587	0.571	FC					
IT_PC	0.612	0.600	0.566	0.739	FC				
IT_SVC	0.510	0.558	0.485	0.566	0.649	FC			
MON	0.674	0.709	0.621	0.575	0.621	0.546	FC		
QUAL	0.290	0.295	0.240	0.265	0.284	0.177	0.302	0.709	
RISK	0.655	0.742	0.595	0.603	0.676	0.618	0.690	0.217	FC

Notes: COEV: Control Environment; RISK: Risk Assessment; COACT: Control Activities; INCOM: Information and Communication; MON: Monitoring; IT_OC: Information Technology Organisational Controls; IT_PC: Information Technology Process Controls; IT_SVC: Information Technology Soft Variables Controls; QUAL: Quality Performance.

The reliability test results also agreed with the rule of thumbs (Table 8); Cronbach's alpha and composite reliability values were more than 0.6 and 0.7, respectively (Chin, Marcolin and Newsted, 2003).

Table 8 – Reliability Test of HEI Quality Performance Construct

Indicator	**Value**
Average Variance Extracted (AVE)	0.502
Cronbach's Alpha	0.910
Composite Reliability	0.892

The validity of the higher-order formative construct was tested by looking at the outer weight and loading and their significance values. The test results shown in Table 9 indicate that each first-order construct contributed positively and significantly to its higher-order construct (Hair et al., 2021). As all criteria had been met, thus, the results of the measurement model test deduced that the final data in this study could be used for structural model assessment (hypothesis testing).

Table 9 – Outer Weight, Loading and Significance Values

First Order Contribution	Outer Weight		Loading	
	Original Sample	P-Values	Original Sample	P-Values
COEV → INCON	0.469	0.096	0.869	0.000
INCOM → INCON	0.000	0.500	0.679	0.000
MON → INCON	0.555	0.028	0.896	0.000
RISASK → INCON	0.352	0.119	0.619	0.000
COACT → INCON	0.368	0.113	0.849	0.000
IT_OC → IT_IC	0.466	0.082	0.910	0.000
IT_PC → IT_IC	0.640	0.037	0.951	0.000
IT_SVC → IT_IC	0.052	0.439	0.625	0.002

Notes: COEV: Control Environment; RISK: Risk Assessment; COACT: Control Activities; INCOM: Information and Communication; MON: Monitoring; IT_OC: Information Technology Organisational Controls; IT_PC: Information Technology Process Controls; IT_SVC: Information Technology Soft Variables Controls; QUAL: Quality Performance.

3.5 Structural Model

The results of the structural model assessment (Table 10) implied that the model with the moderation had a higher adjusted R^2 value (0.107) than that without the moderation of IT_IC (0.098). It indicates, however, that a moderated model was better and was suggested for practical implications (Chin, 1998). This justification was also strengthened by the value of f^2, indicating the effect size of the moderator variable at a moderate level (0.015) (Aguinis et al., 2005). Additionally, the model proposed in this study met the goodness of fit as the SMRM value was less than 0.10 (Henseler et al., 2014).

Table 10 – Summary of Structural Model Assessment Results

Hypothesis	Without Moderation		With Moderation	
	ß	P-Value	ß	P-Value
IT_IC → Internal Control (H_1)	0.788	0.000**	0.788	0.000**
IT_IC → Quality Performance	0.098	0.154	0.098	0.163
Internal Control → Quality Performance	0.236	0.001**	0.311	0.001**
Internal Control*IT_IC → Quality Performance (H_2)			0.100	0.046*
Adjusted R^2	0.098		0.107	
f^2 (Effect size) of IT Controls as Moderator	0.015			
SRMR (model fit)	0.083			

Notes: *P<0.05; **P<0.01.

4 DISCUSSION

In general, this study deduced that IT development for internal control purposes (IT_IC) in Indonesian HEIs was still moderate. However, IT_IC development was indeed positively associated with internal control implementation; thus, H1 was supported. This result affirms previous studies, uncovering that IT development could benefit organisational governance practices (Rubino, Vitolla and Garzoni, 2017; Mazza and Azzali, 2018; Queiroz et al., 2018). In addition, this result confirms that the efforts made by the Indonesian government in encouraging IT development at HEI have had a positive impact, although, in general, the implementation of each dimension of IT_IC was still at a moderate level.

On the other hand, although it was not a hypothesis, the tests also found a positive relationship between internal control and HEI quality performance. Thus, this result expands the findings of previous studies that internal control in the corporate contributes to improving performance (Al-Thuneibat, Al-Rehaily and Basodan, 2015; Länsiluoto, Jokipii and Eklund, 2016). Based on this study's findings, however, internal control was associated not only with financial performance but also with non-economy achievement, i.e., quality performance, which is the main concern of HEI.

Furthermore, from the testing results of both models, with moderation and without moderation, it was discovered that IT_IC was not associated with HEI quality performance, but its role as moderator was significant. As such, it can be deduced that the IT_IC acted as a pure moderator (see Table 10) (Durmusoglu et al., 2014). In other words, the relationship between internal control and HEI quality performance was strengthened by IT_IC development. These results affirm the study by Zhou et al. (2017) and Saeidi et al. (2019) that the orchestration of organisational resources, in this case, IT and internal control, is indispensable in the pursuit of competitive advantage. In contrast to their research in the corporate context, this study presents empirical evidence in the HEI sector, which is for ranking and accreditation in the competition era, both nationally and globally.

From the findings described above, this study initiates both practical and theoretical implications. First, practically, the results of this study suggest that the development and orchestration of IT_IC at HEI should continue to be improved considering the benefits it brings. Even at the moderate implementation level, as this study found, IT_IC development can be positively related to internal control implementation, and strengthened the internal control-quality performance realtionship. Indeed, investing in IT is not cheap and sometimes complicated. However, considering its benefits are also great for increasing organisational capability and competitive advantage, it is important to continue this policy. In fact, many HEIs still consider the implementation of internal control to be done enough with a manual mechanism. Therefore, many of them still have not developed IT_IC today. For regulators, perhaps, the formulation of certain SOPs, guidance or frameworks related to how IT_IC should be developed needs to be done to become a benchmark for HEI.

Theoretically, the results of this study confirm that the orchestration of the organisation's internal resources is pivotal to improving internal capabilities, which are then useful for pursuing competitive advantage. It is evident from the development of IT_IC, which is directly and positively associated with the implementation of internal control. Even IT_IC can strengthen the relationship between internal control and HEI quality performance. Thus, this study complements the resource-based view theory by Barney (1991) that focuses on four criteria that must be met so that internal resources can promote competitive advantage, including valuable, rare, inimitable and non-substitutable. Rather, this study adds that harmonious interaction (orchestration) between internal resources is also crucial to realising sustained competitive advantage. For this purpose, the role of leadership is absolutely vital (Asiaei et al., 2021; Sirmon et al., 2011).

5 CONCLUSION

This study examines the extent of the IT_IC development in HEI in Indonesia after the 2018 government recommendation. It also investigates the IT_IC role in implementing internal control and its role as a moderator in the relationship between internal control and HEI quality performance. By involving 191 HEIs, this study concludes that IT_IC was positively associated with internal control implementation. In addition, IT_IC played a role as the pure moderator; in other words, it strengthened the relationship between internal control and HEI quality performance. Drawing from these insights, this study suggests that IT_IC development should concern HEI management because of its great benefits. From a theoretical point of view, the results of this study strengthened the premise of resource orchestration theory empirically, suggesting that it is necessary to enrich existing internal resources to increase the organisational capability to achieve a competitive advantage. In this study, internal control effectiveness enhancement associated with HEI quality performance can be executed by orchestrating IT_IC development.

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CONFLICTS OF INTEREST

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Identification of the Elements and Systematisation of the Pillars of Solid Waste Management

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ABSTRACT

Purpose: This study identifies elements and systematises them into pillars based on relevant scientific publications on the subject, highlighting actions that contribute to the public authorities and private organisations for developing Solid Waste Management (SWM), contributing to environmental, social, and economic sustainability.

Methodology/Approach: This research used the content analysis method with the aim of identifying the main elements of SWM. To this end, the inductive approach was used to classify in a logical and organised manner the elements identified in the literature and then systematise them into pillars.

Findings: The pillars identified in SWM were: Public Management, Public Policies, Environmental Solutions and Triple Bottom Line.

Research Limitation/Implication: The main limitation of the study is the use of articles between the periods 2014 and 2018.

Originality/Value of paper: The main scientific contribution was to expand and deepen the literature on the subject, articulating concepts in pillars that can be developed and improved according to the characteristics of different regions or localities, improving the use of SWM resources. As to the applied contribution, it was possible to analyse the fields of direct and indirect action of public and private sectors that can be implemented in SWM, improving the understanding of the limits that each stakeholder can contribute to the effectiveness of SWM.

Category: Literature review

Keywords: solid waste management; sustainability; stakeholder engagement; content analysis

1 INTRODUCTION

An estimated one million people die every year in the world because of contamination from solid waste disposed of inappropriately in the environment (Espuny et al., 2021a). With the increase in the rate of urban and population growth, it is estimated that the amount of waste produced on the planet is increasing significantly and is expected to reach 3.4 billion tons by 2050 (World Bank, 2022). Solid waste comes from the generation, consumption and disposal of food, plastics, paper, cardboard, polyethylene terephthalate (PET), glass, textiles, metals, wood, leather, nappies, and ash, among others, in residential, commercial and institutional areas (Tan et al., 2015a; Tozlu, Özahi and Abuşoğlu, 2016). It must be well managed considering its specificity and processed in a complex chain of steps called Solid Waste Management (SWM), so that its environmental, social and economic impacts are mitigated (Anuardo et al., 2022).

The most commonly used solid waste control procedures in SWM are biological treatment, thermal treatment, and landfills, which protect the environment and provide a correct destination for the waste (Tan et al., 2015a). In addition to composting, methods such as incineration are used to eliminate waste, recover energy and reduce the volume of waste generated (Wu et al., 2014). In SWM, collection and transportation can be considered critical factors because their processes are more expensive due to labour intensity and the massive use of vehicles (Das and Bhattacharyya, 2015). To alleviate the waste burden on landfills, recycling has been widely accepted as a sustainable method of SWM (Moh and Abd Manaf, 2014).

Thus, researchers have developed studies of solid waste impacts based on technology and management tools, seeking to identify procedures that treat solid waste efficiently. Ding et al. (2021) identified technologies aimed at SWM from eight eastern coastal regions of China, comparing them with developed cities. Abdallah et al. (2020) compiled 85 studies published between 2004 and 2019, analysing the application of artificial intelligence in SWM, to map software platform that can be implemented in municipalities. Nanda and Berruti (2021) identified the impact of state-of-the-art landfill conditions, discussing volume reduction, resource recovery, and waste valorisation, among others. Vinti et al. (2021) identified 29 studies to assess the impacts of landfills, incinerators, and dumpsites on the health of nearby residents.

However, still scientific gaps that need to be filled to make SWM more efficient through the interaction between public authorities, academia, the private sector, society and other stakeholders (Anuardo et al., 2022). In this sense, approaches that enhance and integrate social, economic, political, technical and environmental aspects of SWM should be elaborated and proposed (Das et al., 2019; Ramos et al., 2022; Bravi et al., 2020; Carvalho et al., 2020; Costa et al., 2019). Thus, this paper has the following research question: what are the main pillars of SWM, and how should the public and private initiatives articulate to boost it? To address this, this study identifies elements and systematises them into pillars based on relevant scientific publications on the subject, highlighting actions that contribute to the public authorities and private organisations to develop SWM.

2 THEORETICAL REFERENTIAL

The main groups of solid waste commonly identified are: municipal, commercial, industrial (in detriment of civil construction), agricultural, and institutional, among others. These wastes are produced in human activities, both at homes and in organisations, and are subject to storage, collection, handling and disposal processes. These processes impact the environment and population, leaving them vulnerable to potential toxicities caused by the lack of adequate management of these wastes (Gupta, Yadav and Kumar, 2015; Araujo et al., 2021).

Social, cultural and economic aspects interfere in the generation of solid waste, which may hinder the return of discarded items in the form of raw materials and increase the complexity of its management (Miezah et al., 2015). The variety and quantity of discarded solid waste have grown significantly over the years as the purchasing power and standard of living increase, the quality of life improves, etc. With this, municipalities are encountering increasingly complex challenges in managing their solid waste properly and effectively (Nabavi-Pelesaraei et al., 2017; Nijkamp and Kourtit, 2017).

SWM is comprehensive and involves steps beyond the collection, such as transportation, separation and final disposal of waste (Beliën, De Boeck and Van Ackere, 2012). One of the first procedures to be fulfilled in SWM is the identification of the most appropriate places for disposal. With this, it is possible to direct the collected waste to separate and final disposal units (Liu et al., 2014). Local collection services absorb approximately 70% of the waste production (Johari et al., 2014).

Effective SWM is essential for the population to have a dignified and healthy life and minimise environmental effects (Gouveia, 2012). It is worth remembering that the articulation of the governors with their citizens is one of the main strategies to reduce the impacts caused by the inefficiency of SWM, improving the quality of life in society (Kaza et al., 2018). However, SWM has faced difficulties due to the characterisation and heterogeneity of the composition of organic and inorganic waste that can negatively impact its separation step and make the recycling process unviable (Miezah et al., 2015; Al-Salem et al., 2017). Solid waste recycling aims to reintroduce the discarded material either in product form or as an input or raw material (Bing et al., 2016). Organic waste can be recycled through composting, which is decomposition by microorganisms in a moisture environment with aerobic and anaerobic characteristics (Gupta, Yadav and Kumar, 2015).

With the intention of promoting effective SWM, the former European Economic Community presented a waste hierarchy and established the priorities in public policies through Council Directive 75/442/EEC (Cucchiella, D'Adamo and Gastaldi, 2014). With this, several nations have instituted similar legislation to regulate and standard waste management processes, with predictions about the practices adopted to be implemented and the protective definitions that States should cherish (Rajaeifar et al., 2015).

In this law process developed by the public sector, companies had more responsibility for SWM in their production process. Despite this accountability, they had several market opportunities, both established and emerging companies (Lima et al., 2014). Opportunities have emerged for recycling cooperatives, energy exploration through biogas or waste burning, consulting services for SWM, urban mining, etc. (Ghisellini and Ulgiati, 2020; Espuny et al., 2021a). The technological development of the last decades (Zgodavova, Lengyel and Golemanov, 2008) has also enabled a significant advance in waste management, as in the case of scrap, making the monitoring and trading of these materials more sophisticated and automated by organisations. Thus, scrap can be reused in production, reducing the demand for virgin raw materials (Mastos et al., 2020).

Companies have also created solutions to implement sensors and software to monitor the complete production cycle, extending the useful life of resources and decreasing waste generation, namely, with lean and green tools (Silva et al., 2020) and 3D printing (Zgodavova et al., 2021). Another sophisticated strategy developed by companies with circular economy contribution is the industrial symbiosis, characterised by the use of waste discarded by a particular company, which can be used as raw material by a different company (da Rocha et al., 2022). Also worth noting is the development by companies of applications to facilitate the marketing of recyclable materials in the B-2-B format in countries such as China and the United States of America. Reliable data mining, being a sensitive point in SWM, has been prioritised for business development to improve waste diagnostics, improving the quality of decisions by public managers (Anuardo et al., 2022).

3 METHODOLOGY

This research can be classified as applied and exploratory, with the approach qualitative. The technical procedures adopted, respectively, were bibliographic research and content analysis (Kothari and Garg, 2019). This research was carried out according to the flow presented in Figure 1, and its stages are described below.

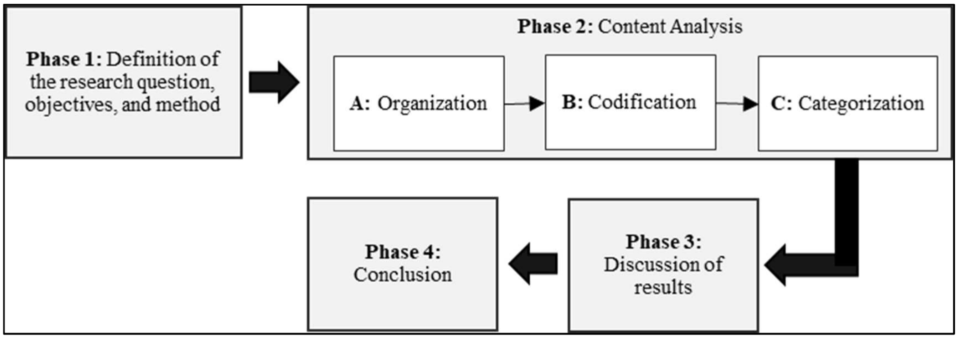

Figure 1 – Methodological Flow

In Phase 1, the research question, objectives, and method were defined. This research used the content analysis method to identify the main elements in SWM (Alvarenga et al., 2021; Costa, Santos and Oliveira, 2021; Espuny et al., 2021a). The articles chosen were from the Scopus database, which encompasses the main ones in the environmental management area (Oliveira et al., 2019). In Phase 2, inductive content analysis was performed with the aim of classifying in a logical and organised way the elements identified in the literature on SWM from the selected articles (Vnoučková, 2018; Kothari and Garg, 2019; Belkind, 2021). This phase followed three stages: Organization, Coding and Categorization. In Organization (Stage A) was performed the search for articles and scientific reviews in the Scopus database, which contained in their titles, keywords and abstract the term "solid waste management". Thus, the 30 most cited scientific documents between the years 2014 and 2018 were selected.

In Coding (Stage B), the elements (words) related to SWM were defined as units of record. Then, the frequency of each element identified in the most cited articles was marked (Appendix, Table A1). Thus, the elements with a low contribution to the topic were discarded. In Categorisation (Stage C), the identified elements were grouped according to their similarities in pillars. In Phase 3, the elaborated pillars were discussed in the light of the most recent scientific literature. In Phase 4, the conclusion was conducted, evidencing the answer to the research question, the objectives attained, the contributions, limitations and suggestions for future works.

4 RESULTS

Based on the 30 articles selected, 15 elements were identified and quantified by their frequency in the articles (Figure 2), then systematised into pillars.

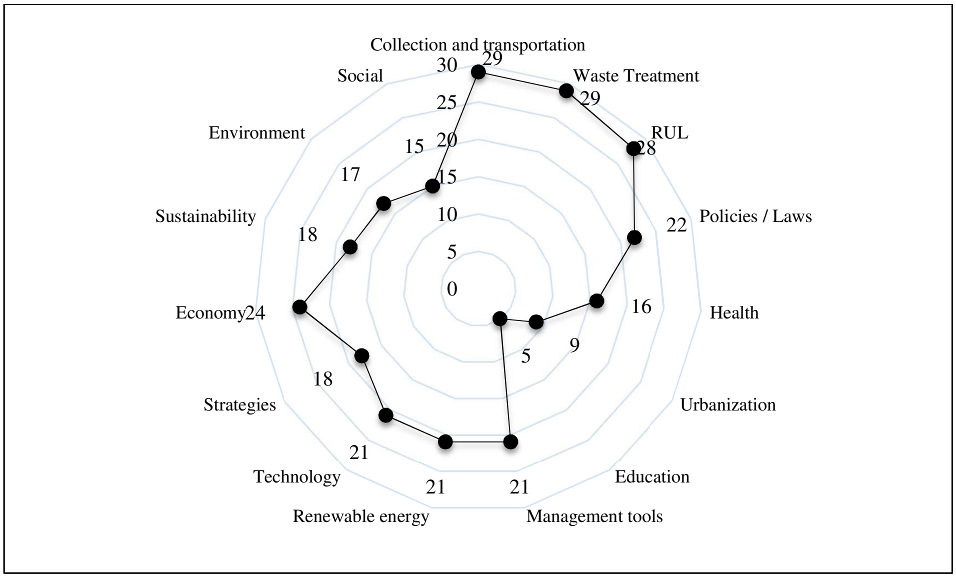

Figure 2 – Elements of SWM

According to Appendix (Table A1), the waste management elements identified were systematised into: Public Management, encompassing the elements collection and transportation, waste treatment and recycling, use and landfill (RUL); Public Policies, which covers policies/laws, health, urbanisation, and education; Environmental Solutions, grouping management tools, renewable energy and technology; and Triple Botton Line (TBL), which brings together economy, sustainability, environment and social. All pillars seek to boost SWM, contributing to the reduction of environmental and social damages.

The pillar of Public Management has preponderant participation of municipal governments and should be managed mainly by the Secretariats of Public Service and the Environment. Some municipalities determine this competence to municipal autarchies, mixed capital companies, or even public-private partnerships (Pan et al., 2018). It is essential that the municipalities participate in this process because SWM is one of the most costly services for the municipal treasury. Rulers must be aware of the financial capacity of the municipality in which they operate because this sector involves campaign promises that often may not be fulfilled. Many times the non-compliance does not occur due to the lack of operational competence of its agents but because the budgets of the municipalities are increasingly immobilised with mandatory expenses, which involve the payroll, education and health, which end up not providing a margin for investments in improvements needed for managing of municipalities. Given these considerations, it should be mentioned that successful waste management is only possible through responsible work on the part of municipal managers (Kaza et al., 2018).

The Public Policies pillar involves the management of the municipal executive authorities in consonance with the legislative authorities, as here are considered the legal factors that can speed up important procedures and projects (Tozlu, Özahi and Abuşoğlu, 2016). It is also considered the co-participation of the Health and Education Secretariats to make the population aware of the importance of changing the attitude of the residents. Also, posture should be changed in practically the entire national territory, both in relation to the attention in recycling their own domestic waste, as well as taking care of the waste of the environment in which it is located, to inhibit the transmission of diseases (Keeble, 1987). Another important issue that must be listed is the alignment that institutions must have in municipal urban planning so that SWM can always be prioritised (Panepinto, Blengini and Genon, 2015). Such negligence allows for the formation of clandestine dumps whose omission by the State may culminate in the contamination of important environmental areas and aquifers (Abd El-Salam and Abu-Zuid, 2015).

The Environmental Solutions pillar aggregates the intelligence differentials that a municipality can use, whether the municipality is the provider of waste solutions or a partner, or even when hiring differentiated services from the private sector (Wilson et al., 2015a). The public authority is not always up to date with the main good practices that the world has developed in the area because the solutions often require high financial investment (Qambrani et al., 2017). Often, it only takes the goodwill of the public employees themselves, such as articulation, to gain the support of the citizens. Developing countries have a significant percentage of organic waste; in this context, it is essential to develop alternative methods to obtain energy from the methane gas generated in landfills (Malinauskaite et al., 2017).

The TBL pillar aggregates the issues of the environment, society, economy, and issues that involve two or three of these aspects is called sustainability. After exploring economic activity with little concern about environmental impacts, as in the 1990s, the analysis of environmental impacts and liabilities arising from human activities began (Elkington, 1994). Within this context, it was possible to analyse the consequences that the lack of criteria in waste management had in the public and private lives of the populations of the planet. Many people still live in the surroundings of dumpsites, collecting part of the materials that exist there to trade it at derisory values (Kaza et al., 2018). Furthermore, people are living next to currently inoperative dumps with foul smells and the presence of animals that are poisonous to the population. For SWM to reach satisfactory rates, it is essential that the population, entrepreneurs from various segments and non-governmental organisations participate together with the government to build an integrated agenda (Nunhes et al., 2021).

When organising the above four pillars, it was found that “Public Management” and “Public Policies” depend solely and exclusively on actions provided by the public sector.

The “Environmental Solutions” and “TBL” pillars depend on public and private initiatives to implement actions that seek to solve environmental problems impacted by SWM (Figure 3).

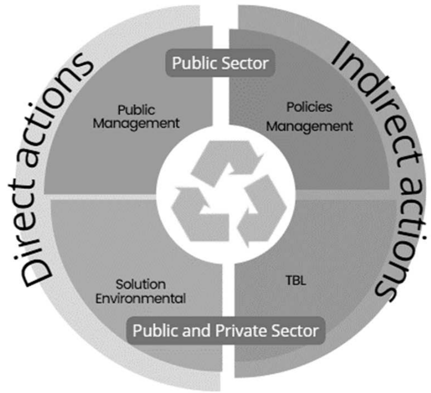

Figure 3 – Stakeholder Interaction for SWM Development

Direct Actions refer to the contributions that intervention by both the “Public Initiative” and the “Public-Private Initiative” can provide to efficient SWM. In the first case, it would be instrumented by Public Management, and in the second case, with Environmental Solutions. Indirect Actions are performed by involuntary aspects but are of great importance in action against “Critical Factors”. These actions are conducted by means of Public Policies, whereby the State is exclusively responsible for mediation, and by the TBL, which might either be promoted by the State or induced by the private sector.

5 DISCUSSION

Public management in municipalities of several developing countries, such as Brazil, China, and India, have sought to improve collection and transportation techniques, treatment, recycling, reuse, and landfills to mitigate the increase in waste generation in municipalities (Fan et al., 2020). Collection and transportation are stages that should complement each other since, in many scenarios, citizens separate organic waste from inorganic waste. However, when the material goes to the truck, the entire content is mixed, reducing the effectiveness of sustainable waste management (Jerin et al., 2022). Additionally, public managers seek alternatives to address by reducing route length, optimising time, waste content and decreasing costs (Hannan et al., 2020). Among waste treatments, technologies focused on thermal conversion (incineration, pyrolysis and gasification) and biological (anaerobic digestion) have been accepted as interesting options for reducing the volume of waste and producing energy at an affordable cost for municipalities (Chen et al., 2019).

Recycling and reuse have become increasingly important for the conservation of virgin material sources, as in the case of metals, plastics and papers, become an essential environmental management strategy, especially for construction and industries (Barbosa et al., 2020; Tang et al., 2020; Silva et al., 2021). Landfills remain the most common method used by municipalities to dispose of their solid waste, but large metropolitan regions have increasingly less space to support this structure. Thus, it becomes necessary to periodically remove waste with the potential for reuse and land reclamation from operating landfills, thereby extending their useful life (Nanda and Berruti, 2021).

Public policies have been developed based on the environmental and economic performance indicators of municipalities so that SWM can be better structured (Paes et al., 2020). The main objectives of the elaboration of these policies are the preservation of citizens' health; reduction of the impact of waste management on the environment; reduction of the expenses of transportation services, collection, treatment and disposal of waste; and energy use of waste (Pujara et al., 2019). Thus, municipalities are always revising their laws and developing actions for public health, urban planning and education (Anuardo et al., 2021). Regarding laws, the major challenge for countries is to attune national laws with local ones, minimise overlapping responsibilities, and drive stakeholder engagement in SWM (Abu Hajar et al., 2020).

The issue that significantly impacts urban planning is the difficulty municipalities have in providing sites for waste treatment and disposal. This ends up impacting the low efficiency of collection and disposal that escapes environmental protocols (Barklign and Gashu, 2021). In the case of education, it is essential that public authorities raise the awareness of society at all age groups and education levels so that citizens dispose of waste at the appropriate sites and properly handle food waste and recyclables (Lee, 2020).

Environmental Solution is a resource that seeks to reconcile the improvement of SWM with the resolution of other problems such as the scarcity of material and energy resources (Espuny et al., 2021b). To improve SWM, public authorities and organisations have developed management methods and strategic planning to meet the needs of each location in a more customised way, considering the purchasing power, consumption habits, behaviour and culture (Lalitha and Fernando, 2019). Additionally, public and private authorities have been dedicated to developing technologies that preserve natural resources, mitigate pollution effects, and recover energy from waste (Azam et al., 2020; Bui et al., 2020).

TBL is a premise that all stakeholders engaged in SWM should incorporate (Nunhes et al., 2022). In addition to the need to preserve the environment and society, SWM's efforts must be directed toward sustainable development so that economic results will emerge in the long term (Bui et al., 2020). Spaces for metropolis landfills are increasingly reduced, and the regions with irregular occupation, especially in developing countries, hinder the optimisation of the routing and waste disposal processes (Azevedo, Scavarda and Caiado, 2019). The workers involved in collection and recycling are in a deplorable situation, and many of them have an income of less than the minimum wage. Thus, these people who are the primary human resources for the operationalisation of SWM cannot maintain their livelihood and remain with no prospect of improved quality of life (Azevedo et al., 2021).

6 CONCLUSION

This article aimed at the proposition of pillars through the most relevant scientific literature on the subject between the period 2014 and 2018. The proposed analysis made it possible to identify the most important and recurrent terms, organising them into 15 elements. Thus, identified elements were systematised into four pillars: Public Management, Public Policies, Environmental Solutions and TBL, seeking to mitigate vulnerabilities arising from the negative impacts of solid waste. In this work, the main scientific contribution was to expand and deepen the literature on the theme, articulating concepts in pillars that can be developed according to the characteristics of different regions or localities, improving the use of human, material and financial resources of SWM. However, the main contribution of this article was to analyse the fields of Direct and Indirect Action of Public and Private authorities that can be implemented in SWM to improve the understanding of the limits that each stakeholder can contribute to the effectiveness of SWM. The main limitation of this work was the selection of only articles and reviews from 2014 to 2018, although the findings were discussed based on the most recent literature. Finally, as a suggestion for future studies, we encourage a more detailed analysis of each proposed pillar, adding information from studies applied in industries and municipalities.

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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

Table A1 – List of Top 30 Articles

Pillars	Public Management				Public Policies			Environmental Solutions				Triple Bottom Line				Total
Elements	Collection and transportation	Waste Treatment	RUL	Policies / Laws	Health	Urbanisation	Education	Management tools	Renewable energy	Technology	Strategies	Economy	Sustainability	Environment	Social	
Laurent et al. (2014a)	x	x	x	x	x	x		x	x	x	x	x	x	x	x	14
Laurent et al. (2014b)	x	x	x	x	x			x	x	x	x	x	x	x	x	13
Lim, Lee and Wu (2015)	x	x	x		x	x		x	x	x	x	x		x	x	12
Chen et al. (2014)	x	x	x		x				x	x		x		x		8
Soltani et al. (2015)	x	x	x	x	x			x	x	x	x	x	x	x	x	13
Edjabou et al. (2015)	x	x	x	x				x		x						6
Tan et al. (2015b)	x	x	x	x				x	x	x	x	x		x		10
Ghiani et al. (2014)	x	x	x		x	x		x	x	x	x	x	x	x	x	13
Erses Yay (2015)		x	x		x				x	x	x	x	x	x		9
Agyeman and Tao (2014)	x	x	x	x	x		x	x	x	x	x	x	x	x		13
Allesch and Brunner (2014)	x	x	x	x	x		x	x		x	x	x	x			11
Moh and Abd Manaf (2014)	x	x	x	x		x	x			x	x	x	x		x	11
Al-Salem et al. (2017)	x	x	x	x	x			x	x	x	x	x	x	x		12
Torretta et al. (2015)	x	x	x						x			x				5
Alibardi and Cossu (2015)	x	x	x	x		x	x	x								7
Tan et al. (2014)	x	x	x	x		x		x	x	x	x	x	x		x	12
Abd El-Salam and Abu-Zuid (2015)	x	x		x					x	x		x	x		x	8

Pillars	**Public Management**				**Public Policies**			**Environmental Solutions**				**Triple Bottom Line**				**Total**
Elements	Collection and transportation	Waste Treatment	RUL	Policies / Laws	Health	Urbanisation	Education	Management tools	Renewable energy	Technology	Strategies	Economy	Sustainability	Environment	Social	
Miezah et al. (2015)	x	x	x	x	x	x			x	x		x	x	x	x	12
Gupta, Yadav and Kumar (2015)	x	x	x		x				x		x					6
Ariunbaatar et al. (2014)	x	x	x	x	x			x	x	x		x		x	x	11
Nabavi-Pelesaraei et al. (2017)	x	x	x		x	x		x			x		x	x	x	10
Naveen et al. (2017)	x	x		x					x				x			5
Das and Bhattacharyya (2015)	x	x	x	x				x			x	x			x	8
Aghajani Mir et al. (2016)	x	x	x	x	x		x	x	x	x	x	x	x	x	x	14
Wilson et al. (2015b)	x	x	x	x				x	x	x		x	x	x		10
Liu et al. (2014)	x	x	x	x				x				x				6
Wu et al. (2014)	x	x	x	x	x			x	x		x	x	x	x	x	12
Rada and Ragazzi (2014)	x	x	x			x		x		x	x		x	x	x	10
Basso et al. (2015)	x	x	x	x					x	x		x				7
Fernández-Nava et al. (2014)	x		x	x				x				x				5
Total	29	29	28	22	16	9	5	21	21	21	18	24	18	17	15	

Designing Socio-Technical Systems Using the System Paradigm in the Context of Nano-, Bio-, Information Technology and Cognitive Science Convergence

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ABSTRACT

Purpose: The purpose of the study is to develop a methodology for designing socio-technical systems using the system paradigm in the context of nano-, bio-, information technology and cognitive science convergence.

Methodology/Approach: The systemic paradigm is used. The optimization is carried out according to the integral indicator of resource consumption and system energy efficiency. Fractal socio-technical systems are created that provide the maximum correlation between the needs of individuals and the activities of society, taking into account the dynamics of the formation of needs for the purpose of self-development with restrictions on safety factors and material resources.

Findings: The proposed methodology makes it possible to develop socio-technical systems with a high level of security, ensuring sustainable spiral self-development and integration of scientific knowledge on the basis of adaptive, innovative, intuitive and analytical elements of the system.

Research Limitation/Implication: A general concept for designing socio-technical systems using the system paradigm in the context of nano-, bio-, information technology and cognitive science convergence is presented that requires further research.

Originality/Value of paper: A methodology for designing socio-technical systems using the system paradigm in the context of nano-, bio-, information technology and cognitive science convergence was first proposed.

Category: Conceptual paper

Keywords: socio-technical system; system paradigm; nano-, bio-, information technology and cognitive science convergence; quality of life; self-development

1 INTRODUCTION

In socio-technical systems, the nature of effective nano-, bio-, information technology and cognitive science convergence (NBIC convergence) should imply the following principles:

- multifactorial generation and modification of products by means of nanotechnological principles used in physicochemical and biological production systems;
- renewability of resources;
- increasing energy efficiency;
- obtaining, analyzing and synthesizing data on system components in real time;
- high level of security in decision making;
- increased correlation between consumer and producer;
- integration of scientific knowledge;
- development of cognitive human and machine processes.

To ensure NBIC convergence and to solve many of the presented issues, the design of systems should be carried out, taking into account the entire complex of existing processes. The systemic paradigm mentioned in the works of J. Kornai (Kolbachev, Halász and Fedorchuk, 2019) makes it possible to implement such an approach.

In addition, the optimization of technical systems currently involves mainly minimizing resource and energy investment (Winkler-Goldstein et al., 2018). Modern digital technologies make it possible to quickly obtain data, including in real-time and calculate the energy and resource consumption of technological processes and production facilities throughout the PLM cycle. In view of the existing potential threats, it is important to create principles that allow the socio-technical system to develop steadily.

The purpose of the study is to develop a methodology for designing socio-technical systems using the system paradigm in the context of NBIC convergence. To do this, it is necessary to solve the following tasks:

- to ensure the implementation of nanotechnological principles of physical, chemical and biological production systems;
- define criteria for assessing resource consumption and energy efficiency, calculated on the basis of data on system components in real-time;
- to develop mechanisms for creating fractal socio-technical systems that provide a high correlation between the individual, production systems and society, based on the dynamic criterion of the quality of life;

- to propose a structure with a high level of security, ensuring sustainable spiral self-development and integration of scientific knowledge based on adaptive, innovative, intuitive and analytical elements of the system.

2 PRINCIPLES FOR THE DESIGN OF PRODUCTION SYSTEMS BASED ON NANOTECHNOLOGY

Nanotechnology has both technological and social benefits (Aithal and Aithal, 2016):

- providing a wide range of functional properties of materials;
- the possibility of reducing the size of products;
- production efficiency and reduction in the use of energy and other resources;
- the ability to change the human technological environment;
- after full implementation, ensuring the security of the world economy;
- solving the problems of social interaction and health problems.

Nanotechnology is fundamentally transforming existing production systems by applying the following principles to their design:

- management of functional characteristics at the nanoscale;
- parallelization of the processes of material and product formation;
- self-organization of the system, including cognitive artificial intelligence.

Thus, the main tasks in the design of such systems are:

- assurance of the effectiveness of application in various industries;
- ensuring productivity;
- safety and manageability.

The efficiency of production systems developed on the basis of nanotechnology directly depends on the availability of mechanisms that ensure the rapid integration of scientific achievements.

In ideological terms, nanotechnology offers a certain perspective that will allow:

- drastically minimize resource consumption with the possibility of raw materials recovering;
- to unify the applied technological tools as much as possible;
- to shorten the technological process of manufacturing products, ensuring high energy efficiency.

The possibility of developing production systems based on nanotechnology is primarily due to the socio-technical paradigm within which they exist. Thus, at present, the use of nanotechnology has found itself in medicine, electronics, and the chemical industry but is still poorly expressed in other areas of industrial production. This is due to the fact that the main target factor of production is productivity and financial profit, while in this case, it is necessary that the production system, when designing, be focused on the quality of life of consumers and manufacturers, as the main task, and take this into account in the parameters of its efficiency. Here, quality and functional orientation, intellectual self-organization and modification should be considered as complex system parameters, the analysis of which considers the impact on all elements of the socio-technical system, including the factor of inheritance.

3 CRITERIA FOR ASSESSING RESOURCE CONSUMPTION AND ENERGY EFFICIENCY

It makes sense to assess resource costs in terms of resource efficiency and the circular economy, in particular, the retention of resources within the economy (Di Maio et al., 2017).

In terms of resources, the circular economy focuses on reuse and recovery. In some cases, creating a closed loop requires more energy. Waste, loss and degradation of resources are never zero, so additional resources and materials are required to close the loops. All of this additional effort needs to be evaluated and compared with the benefits of closed resource savings. To assess resources, global indicators are being developed that, in addition to simple depletion potential, take into account the impact of resource life cycles, recyclability and geopolitical availability, covering all types of resources (renewable and non-renewable) (Adibi et al., 2017).

The integral indicator of resource consumption should take into account the following characteristics of resources in the system under consideration, expressed through weight coefficients:

- geopolitical accessibility,
- existing volume,
- cost of production,
- cost of processing,
- renewability,
- cost of the renewal.

In the context of NBIC convergence, the formation of resources should be as flexible and diversified as possible in terms of obtaining them.

Energy efficiency and energy flexibility are becoming increasingly important. Energy management is often based on ISO 50001:2018 standards and norms. Within Industry 4.0, manufacturing plants use cloud-based energy monitoring and management systems. This solution enables real-time production control, enabling flexible energy planning based on historical data and energy management (Javied et al., 2018). Systemic energy efficiency is the next criterion to be applied is the efficiency of using energy, material and cognitive resources. The same systemic energy efficiency can be provided with a different percentage of one or another component.

4 MECHANISMS FOR CREATING FRACTAL SOCIO-TECHNICAL SYSTEMS

Quality of life is a complex concept that includes not only economic factors but also intangible components (Girard et al., 2017). The Commission on Basic Indicators of Economic Performance and Social Progress (Stiglitz-Sen-Fitoussi Commission cited in Eurostat, 2017) measures 9 factors (Table 1).

Table 1 – Factors & Indicators that Determine the Quality of Life (Eurostat, 2017)

Factor	**Index**
Material housing conditions	Average income
	Income inequality quintile S80 / S20
	Material deprivation index
Industrial or other main activity	Employment rate
	Job satisfaction
Health	Average life expectancy
	Self-reported health status
Education	Percentage of people with higher education
Leisure and social interaction	Time satisfaction
	Help from others
Economic and physical security	Inability to afford incidental expenses
	Number of murders
	Perception of crime, violence or vandalism in a residential area
Public administration and fundamental rights	Trust in the legal system
Natural and living environment	Urban pollution
	Perception of pollution or other environmental issues in a residential area
Shared life experience	Life satisfaction

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Table 1 contains both objective and subjective indicators. Satisfaction with life, work and quality of free time are not directly a function of economic and social well-being. In this case, the psychological perception of the world, conditioned by the comparison of the level of one's own development and the possibilities of realization provided by society, will be decisive.

The quality of life is a concept that is rather amorphous, difficult to measure, multifaceted, influencing and interacting with various environments and habitat, and can be defined as the sum of the biological and physiological states of a person, lifestyle, as well as personal and social relationships. Due to the fact that people differ from each other in their preferences, needs, economic opportunities and many other aspects, the environment does not provide them with an equal living environment that best suits their unique characteristics and aspirations. (Erdoğan and Namlı, 2019)

Assessment of the quality of life, therefore, should reflect in the dynamics the realization of the needs of an individual and society, since in the process of his development, a person's perception of the world transforms and needs change. In classical socio-technical systems, we contemplate the hierarchy of needs by A. Maslow (2008), based on behaviourist, Freudian and humanistic philosophy. Needs are presented in the form of a hierarchical structure: physiological needs and four levels of psychological needs (safety, love, respect and self-actualization). Satisfaction of higher needs brings greater happiness and contributes to the development of personality, which is the basis of psychological health. S.B. Kaverin (1987) proposes a matrix classification that indicates the need for parallel rather than sequential shaping of needs. Factors associated with work, communication, cognition and recreation go through four stages of their evolution: biogenic, psychophysiological, sociogenic and higher. In the context of NBIC convergence, when the integration of scientific knowledge (Sydorova et al., 2020) becomes a determining factor, a person's needs should, to a greater extent, include a cognitive component. The intellectual, cultural and creative development of an individual enriches the perception of the world around; thanks to the evolution of psychological perception, it becomes more voluminous and multifaceted. Basic human needs do not disappear but are qualitatively transformed and redistributed as a percentage.

Classical social and production systems focused on increasing production, and consumption volumes cannot meet these challenges. For example, forming certain niches to satisfy the needs of self-actualization, only the creation of certain conditions expressed by goods and services occurs, and not the real development of this factor, which ultimately will give low indicators in satisfaction with the quality of life. Thus, when building socio-technical systems should provide for fractal principles for the integration of the system paradigm: the conditions of an individual's existence should imply a complex perception of the world, on the basis of which his needs should be formed, and the system itself should integrate personal needs and the individual, offering an appropriate level of quality of life for their implementation.

Figure 1 shows the matrices of the needs of N individuals I, including physical needs N^p, cognitive needs N^c and social needs N^s. The activity of individual A is respectively represented by physical activity A^p, cognitive activity A^c and social activity A^s. The totality of the needs and activities of individuals determines the matrix of needs and activities of the society. The needs of the society are realized through the activities of individuals, and the activities of the society meet the needs of individuals. In this case, the system should be self-developing and create conditions for the qualitative development of the needs of individuals.

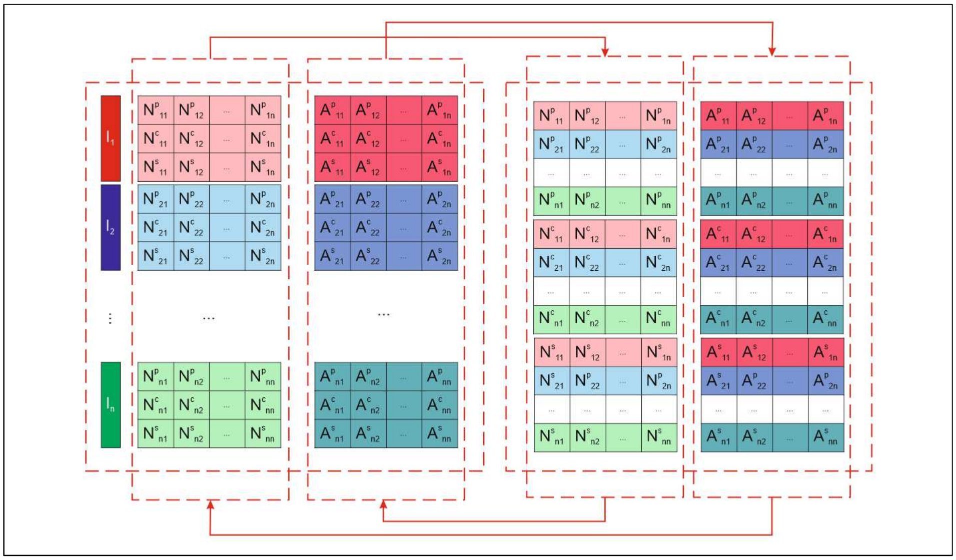

Figure 1 – Fractal Principles for the Integration of the System Paradigm in Socio-Technical System

The next important issue is to determine the mutual influence of the physical, cognitive and social needs of individuals in society. The formation of needs can be carried out along different paths. Human evolution generates new needs, which, in turn, can exclude old ones. The needs matrix is dynamic and changes over time. For example, cognitive needs can diminish physical ones. At the same time, material resource costs are reduced. The problem of optimizing the socio-technical system will be to ensure the maximum correlation between the needs of individuals and the activities of society, taking into account the dynamics of the formation of needs for self-development. The constraints are safety factors and material resources.

The dynamics of the formation of needs can be studied in different time frames (Figure 2). The time cut can be considered as a certain time interval t in which an individual realizes physical N^p, cognitive N^c and social N^s needs:

$$t_i(N^p) + t_i(N^c) + t_i(N^s) = const. \qquad (1)$$

The percentage of time spent on meeting needs may vary, but their sum is always constant. The change in the function *t(N)* may be due to the evolution of the activity function *t(A)*:

$$t(N) = f(t(A)). \tag{2}$$

If the content of demand *N* remains the same:

$$N = \sum_{i=1}^{n} N_i, \tag{3}$$

then we will talk about a change in its "density": the same needs are realized in a different form over a different period of time.

Nevertheless, the content of the need *N* can change qualitatively and quantitatively, while the function *t(N)* can remain constant or change.

Taking into account the systemic paradigm, the evolution of any need goes through the following stages:

- change in the "density" *N*, provided by the evolution of the activity function *A*;
- quantitative change in *N*, allowing the accumulation of experience;
- qualitative change for the transition to a new stage in the evolution of *N*.

The stable dynamics of the formation of needs and the correlation of activities in socio-technical systems can be implemented on the basis of the principles of spiral self-development.

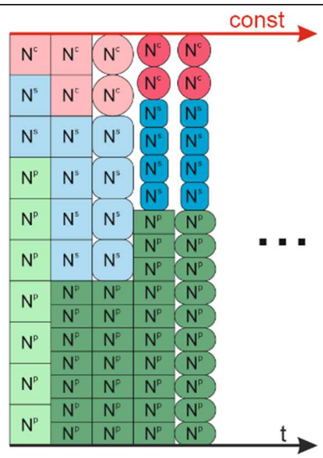

Figure 2 – Evolution of Needs: A Change in the Shape of Elements Indicates Their Qualitative Transformation, And The Lightness of Colour Indicates a Change in "Density"

5 SYSTEM STRUCTURE FOR SUSTAINABLE SPIRAL SELF-DEVELOPMENT

Due to the complexity of the created systems within the framework of NBIC convergence and the global level of potential threats, security can be guaranteed through a decentralized system of collective decision-making in the blockchain (Sydorova et al., 2021). Depending on the nature of the problem, a combination of decision-making experts is automatically determined based on a rating system. An expert can be either a person H or a machine M. The rating for each set of competencies is formed on the basis of the performance assessment by pairs H-H, H-M, M-H, M-M. Man evaluates the performance of machines and other participants in the same way that a machine evaluates the performance of humans and other machines. This is how an integrated rating is formed for the sets of competencies for humans and machines.

In addition, the design of socio-technical systems should imply the presence of mechanisms for introspection and self-development. It is important to determine the optimal conditions for the integration of innovations based on two fundamental points:

- innovations make it possible to meet new needs of individuals or provide old ones in a new qualitative form;
- innovation can shape new needs of individuals.

To ensure the self-development of the system, a qualitatively new formation of the needs of individuals should be formed, allowing to move to the highest stage of development, according to S.B. Kaverin (1987).

The cognitive style of an employee determines the way of searching, processing, evaluating, processing, systematizing and interpreting information. Analysts prefer linear logic and orderliness, methods of analysis. Intuitives take a holistic approach, methods of synthesis, and consideration of the environment or the situation as a whole. Such forms are rare in their pure form. As a rule, they are presented in some combination. They also distinguish between analytic thinkers and innovators. Analytic thinkers prefer to work within a consistent paradigm and are adept at improving existing ways of doing things. In contrast, innovators are more likely to solve the problem by changing the existing paradigm. (Güngör and Alp, 2019)

The socio-technical system should be based on the optimal cognitive structure of analytic and intuitive workers, analytic thinkers and innovators (Figure 3). Analytic thinkers ensure the stability and safety of the system, and innovators ensure its high-quality self-development.

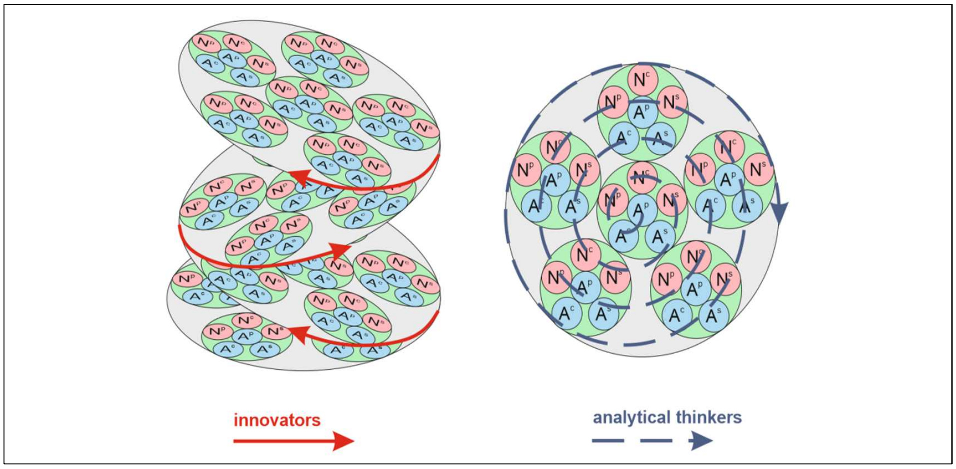

Figure 3 – Innovators and Analytical Thinkers in Fractal Socio-Technical Systems

Such a system will ensure sustainable self-development since each turn will create a stable base for the transition to the next level, while the correlation of activities and needs will be maximum.

6 CONCLUSION

The developed methodology for designing socio-technical systems using the system paradigm in the context of NBIC convergence includes:

- implementation of the principles of designing production systems based on nanotechnology with a radical minimization of resource consumption and the possibility of recovering raw materials, maximum unification of the applied technological tools, reduction of the technological process of manufacturing products and ensuring high energy efficiency;
- optimization according to the integral indicator of resource consumption and system energy efficiency;
- creation of fractal socio-technical systems that ensure the maximum correlation between the needs of individuals and the activities of society, taking into account the dynamics of the formation of needs for the purpose of self-development with restrictions on safety factors and material resources;
- creation of the structure of the system, ensuring sustainable spiral self-development.

The proposed methodology makes it possible to develop socio-technical systems with a high level of security, ensuring sustainable spiral self-development and integration of scientific knowledge on the basis of adaptive, innovative, intuitive and analytical elements of the system.

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AUTHOR CONTRIBUTIONS

Conceptualization, E.S.; Methodology, E.S.; Software, E.S.; Validation, E.S., A.P. and S.H.; Formal analysis, E.S.; Investigation, E.S.; Resources, E.S.; Data curation, E.S.; Original draft preparation, E.S.; Review and editing, E.S. and A.P.; Visualization, E.S.; Supervision, E.S.; Project administration, A.P. and S.H.; Funding acquisition, A.P. and S.H.

CONFLICTS OF INTEREST

The author declares 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.