New Paradigm of Lean Six Sigma in the 4th Industrial Revolution Era

DOI: 10.12776/QIP.V24I1.1430

Sung Hyun Park, Su Mi Dhalgaard-Park, Dong-Chun Kim

Received: 2020-01-24 Accepted: 2020-03-25 Published: 2020-03-31

ABSTRACT

Purpose: In early 2000s Six Sigma and Lean were combined into Lean Six Sigma (LSS), which has been one of the major strategic quality initiatives all over the world. Now, we are in the era of the 4th Industrial Revolution (IR), which changes almost everything including LSS and quality management (QM) in the companies. We need new paradigm of LSS to boost LSS activities in this 4th IR era. In this paper, the typical characteristics of the 4th IR are investigated, and desirable new paradigm of LSS is presented.

Methodology/Approach: The changing characteristics of production strategy, quality goal and quality strategy with regard to QM in the 4th IR are discussed and presented. Then the new and emerging paradigm of LSS in this 4th IR era is discussed in detail. Also 9 success factors for this new paradigm of LSS are shown for practitioners in the industry.

Findings: The direction of the new paradigm of LSS will be ‘simple, speedy and smart’, which may be called ‘3S paradigm’. Simple open procedures and simple statistical modelling tools will be mainly used. Speedy on-site improvement based on Open Data, Big Data and artificial intelligence (AI) will be favoured. Also smart mass customized ‘Smart Factory’ method will be emphasized.

Research Limitation/implication: Since we are in the beginning stage of the 4th IR, there are not many research papers which study the impact of this revolution to LSS and QM, which is the major research limitation.

Originality/Value of paper: This paper suggests some new and emerging paradigm of LSS, which could be of high value.

Category: Conceptual paper

Keywords: Six Sigma; Lean; Lean Six Sigma; 4th industrial revolution; quality responsibility

1 INTRODUCTION

Six Sigma and Lean are two quality management approaches that have received much attention and publicity to improve management processes over the past few decades. Six Sigma was first developed at Motorola in 1987 with remarkable results. In early 1990s, some leading electronic companies such as IBM, DEC, and Texas Instruments launched the Six Sigma approach. From 1995 when GE and Allied Sigma adopted Six Sigma as strategic initiatives, a rapid dissemination took place in non-electronic industries all over the world. Harry (1998), who is a well-known expert in Six Sigma, defines Six Sigma to be "a strategic initiative to boost profitability, increase market share and improve customer satisfaction through the use of statistical tools that can lead to breakthrough quantum gains in quality". Later, Six Sigma was expanded to Design for Six Sigma (DFSS) for R&D and service activities. A good reference for DFSS is Park and Antony (2008). For a complete handbook for Six Sigma, see Pyzdek (2001), and to understand Six Sigma for quality and productivity promotion, see Park (2003). A recent literature review on Six Sigma can be found in Sony et al. (2019).

Lean manufacturing or Lean production, often simply called 'Lean', is a systematic method for waste minimization and value management within a manufacturing system without sacrificing productivity. Mass production systems based on work flow and the conveyer belt inspired Ohno (1978) to develop the Toyota Production System (TPS). The TPS was later coined as Lean in 1988 by Krafcik (1988), and then later by Womack, Jones and Roos (1990). The goal of Lean is to increase speed through the relentless elimination of waste and reduction of non-value-added activities from the processes. Womack and Jones (2003) define Lean as a tool for waste banishment and value creation. Recent references for literature review on Lean manufacturing are Bhamu and Sangwan (2014), Jasti and Kodali (2015) and Psomas and Antony (2019).

Both Six Sigma and Lean focus on customer satisfaction and improved business performance, and they use project management to improve results. However, if we compare both initiatives, we can find the clear differences as shown in Table 1 below. Good references to compare Six Sigma with Lean production are Dahlgaard and Dahlgaard-Park (2006), Andersson, Eriksson and Torstensson (2006), Arnheiter and Maleyeff (2005), Bendell (2006), Nave (2002) and Pacheco et al. (2015). Those references also show a detailed and historical analysis of Six Sigma, Lean production and Total Quality Management combined with a focus on the human factor and the needed corporate culture.

Table 1 – Comparison between Six Sigma and Lean

Initiative	**Six Sigma**	**Lean**
Theoretical Basis	Reduce variation	Remove wastes
Application guidelines	1. Define 2. Measure 3. Analyse 4. Improve 5. Control	1. Identify value 2. Identify value stream 3. Flow 4. Pull 5. Perfection
Focus	Problem focused	Flow focused
Primary effect	Uniform process output	Reduced lead time
Criticism	• System interaction not much considered • Process improved independently	• Statistical or system analysis not valued

The theoretical basis and focus of Six Sigma is the reduction of variation (of products/ product components) in the process, while that of Lean is the removal of wastes in the process. The major application guidelines for Six Sigma are DMAIC (Define, Measure, Analyse, Improve and Control), but those of Lean are IIFPP (Identify value, Identify value stream, Flow, Pull and perfection). The focus of Six Sigma is ‘problem’, but that of Lean is ‘flow’. The primary effect of Six Sigma is uniform process output by reducing variations of the process, but that of Lean is reduced lead time in the process. However, both initiatives have some criticisms. Six Sigma is criticized in that system interaction is not much considered, and, since each process is improved independently, the overall process may not be improved. Lean is criticized for not paying high importance to statistical and system analysis of each process.

Combining the theoretical bases, application guidelines and focuses of these two improvement approaches, the concept of LSS was first created by Wheat, Mills and Carnell (2001), and explained in detail by George (2002) and George (2010). LSS is a synergized managerial concept of Six Sigma and Lean (see also Hoerl and Gardner (2010), and Jugulum and Samuel (2008)). It combines the strengths of Six Sigma and Lean, and becomes more powerful for solving many practical problems.

As shown in the house of LSS of Figure 1, the goal of LSS is achieving ‘high value and quality, minimum waste and variation’ to be a world class company for stakeholder satisfaction. In order to achieve this goal, two big pillars are needed. The first is the Lean approach by speed acceleration and waste reduction for process innovation. The second is the Six Sigma approach by reducing variation, defects reduction and efficient process flow using continuous improvements and innovation. For these two pillars, project team efforts for continuous improvement are necessary. The base of the house is standardization and creating facts by data. Therefore, a sound data management system is absolutely necessary for a good LSS management.

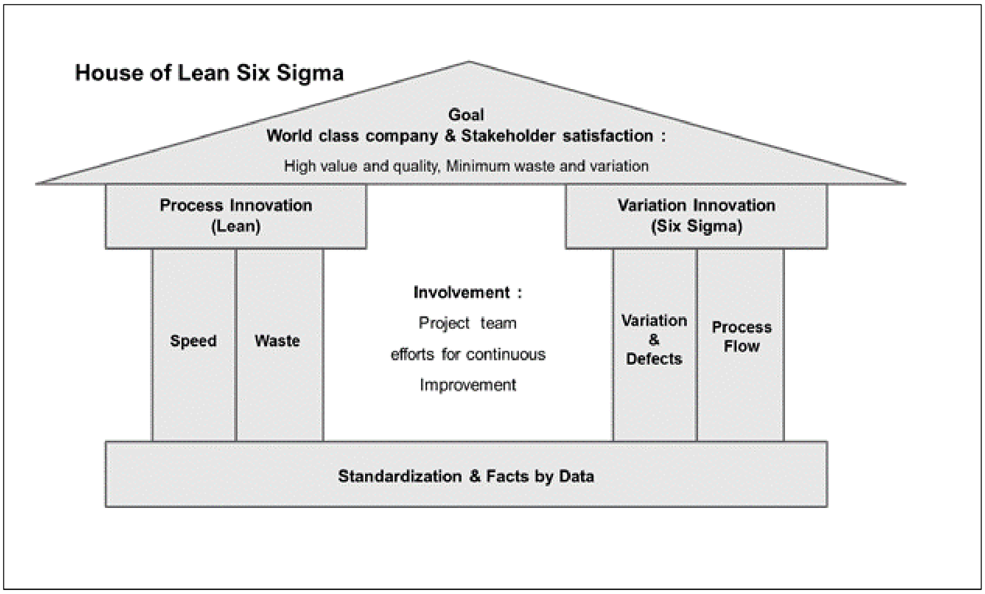


Figure 1 – Combining Lean and Six Sigma - House of Lean Six Sigma

Another point of view for LSS is that LSS allows not only process innovation with speed and waste reduction (by Lean), but also process efficiency with variation & defects reduction and efficient process flow (by Six Sigma). This concept may be called ‘Lean Design for Six Sigma’ which goes to ‘LSS Process Management’. This concept is graphically shown in Figure 2 for the essence of LSS.

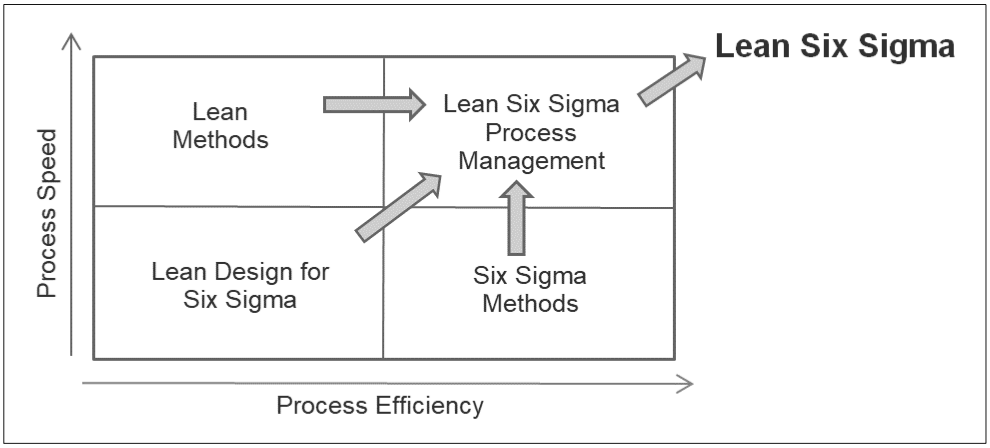


Figure 2 – The Essence of Lean Six Sigma for its Process Management

2 THE 4TH INDUSTRIAL REVOLUTION AND ITS IMPACT ON QUALITY MANAGEMENT

The 4th IR is now with us, and it is characterized by a convergence of physical and cyber technologies to produce intelligent digital transformation. While the term Industry 4.0 has been used since 2011 for referring and addressing the widespread integration of advanced information and communication technology for industrial purposes, Professor Schwab (2015) first introduced the term of 4th IR, and the major theme of the 2016 World Economic Forum was the impact of the 4th IR. However, we can also find cases where other people ‘warned’ the arrival of a new industrial revolution. For instance, prior to Schwab (2015), Cameron (2014) delivered a speech referring to the emergence of internet of things (IoT), ‘a new industrial revolution that will boost productivity, keep us healthier, make transport more efficient, reduce energy needs and tackle climate change’.

While previously recognized, industrial revolutions are all characterised by their significant capability to transform businesses, industrial structures, workforces, and even society in broad aspects, we are now witnessing a new wave of industrial revolution. We now live in a world in which billions of people can be connected to each other through mobile devices with unlimited access to knowledge with the help of emerging technologies such as artificial intelligence (AI), Big Data, robotics, IoT, cloud computing and more. The 4th IR is really changing all aspects of human life including the culture of Quality Management in industry as mentioned in Park et al. (2017).

The 1st IR began in England in the late 18th century, and introduced steam-powered and mechanized production. The Second began in the U.S. in the early 20th century, and introduced electric power and mass-production processes. The Third, which also began in the U.S. in the middle of the 20th century, introduced computers and the digitalization of technology. The 4th IR, which began in the early 21st century, and its characteristics with regard to QM, are shown in Figure 3. As far as production strategy is concerned, mass customization and personalized production will be popular in the 4th IR, since fast IT, customer Big Data and smart factory implementation become available. Before the 4th IR, machine production, mass production and lean production were the major production strategies. In the 4th IR, the speed of production, after delivery service, feedback of customer demands and others, will become increasingly important factors in QM.

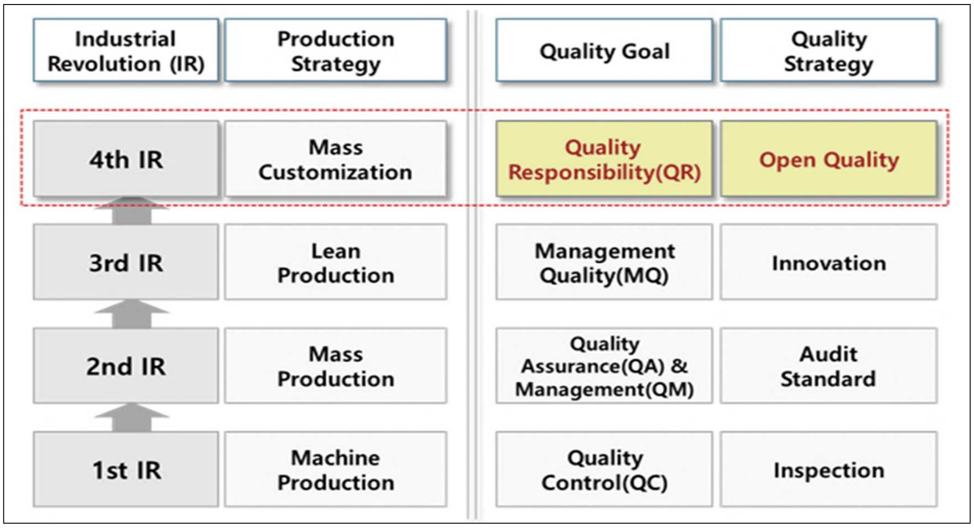


Figure 3 – The Four Stages of IR, Production Strategy, Quality Goal and Quality Strategy

From the evolution of quality in Figure 3 we have observed that the quality goals, scopes and focusing areas have been changing constantly in accordance to the environmental and technological changes (Dahlgaard and Dahlgaard-Park, 2006). For example, Quality Goals was changed or expanded from the 1st IR to the 4th IR as follows: Quality Control (QC), Quality Assurance (QA) and Quality Management (QM), Management of Quality (MQ), and finally we may say that the goal of quality in this 4th IR includes Quality Responsibility (QR). In the 4th IR era, not only the personalized service quality, but also the design, safety and brand quality become more important than before. With innovative technology for connectivity and smart computation, the ability to trace quality for each customer is being maximized in all product and service characteristics. Quality responsibility (or accountability) to all customers, the environment and society are required. For this purpose, the concept of social responsibility, introduced by ISO 26000, is added to quality responsibility. Also the concept of 'green' LSS will be pursued to make the world be a better living place. More explanation about "green LSS" is required.

The changes/ evolution in quality strategies according to the four stages of IR are from inspection, audit and standards, innovation, to Open Quality for the 4th IR. The changes in quality goals and strategies are results of purposeful efforts paid by organizations in order to improve both the internal processes and the external relationships of organizations. The managerial framework of TQM that emerged in the last part of the third stage can be considered as a kind of culmination that provided comprehensive tools and techniques, and principles for achieving organizational wide improvements. For instance principles of customer focus, relationship with suppliers, competitors, communication and deal with quality improvements specifically in relationships outside the organization, while other principles such as top management commitment, leadership, focus on employees, process management focus on the improvement of internal aspects of organizations are basic principles (Singh and Smith, 2004). When combining all TQM principles, tools and techniques, the organizations can be equipped with a managerial framework, which can be applied to strengthen efficiency as well as effectiveness and due to that TQM has been considered to be a holistic management framework (Dahlgaard-Park et al., 2013).

Chesbrough (2011; 2012) referred to closed innovation when the processes, products and services are the results of internal organizational innovation. That's why closed innovation is also called as vertical development because the innovation is happening within the organizational boundary. However open innovation is characterized by the integration of external knowledge with the internal knowledge of the organization, and due to that the issue of continuously identifying and measuring customer needs and desires in a cost effective way has been recognized to be one of the biggest challenges when implementing open innovation (Van de Vrande et al., 2009). Encouraging the customers and involving other external stakeholders in the innovation processes along with encouraging, motivating and involving employees has been equally emphasized, since the innovation process requires a combination of internal and external knowledge (West and Gallagher, 2006). The close relationship with the customers and the constant work with them have been emphasized as a critical success factor of the open innovation, not only in production but also in services (Chesbrough, 2003; 2012).

Identifying customers' needs and desires and thereby involving customers for gaining customer satisfaction has long been recognized to be the most important goal, and internal process improvements, focus on employees as well as other internal improvements activities have been targeted to support that goal within the TQM framework. In this way we can say that there are many similarities and close relationship between TQM and open innovation approaches. In many ways, the implementation of TQM nurtures and creates a proper organizational culture that is also recognized to be necessary for open innovation (Maistry, Hurreeram and Ramessur, 2017). Based on this background we propose using the term, 'open quality' as a new quality strategy. The open quality will be a good and proper solution for organizations in responding to multiple challenges emerged by not only the rapid technological development but also by the increasing globalization.

Open quality accounts for all quality characteristics of any product and service that are designed, produced, marketed, and sold based on open and transparent approaches. The word 'open' is used here to guarantee that the data generated in each section of a company are open to the other sections of the company. Furthermore, the data generated for a particular product of a company are open to external stakeholders/companies to openly promote the overall quality and productivity of the product. This goal can be attained through an open quality system where key factors such as speed, creativity, data analytics, and AI are combined to provide a comprehensive approach for meeting dynamic consumer requirements.

Quality of data and software will be a critical issue in the 4th IR era, because most technologies such as Big Data, AI and IoT are all based on data and software. Eventually, the data and QM supporting software becomes more important; simple and smart QM systems will be necessary. A well designed simple and smart QM system for handling data and software may have the highest value in the 4th IR era.

3 NEW PARADIGM OF LEAN SIX SIGMA AND ITS ENABLERS

It is the authors' belief that the new paradigm of LSS will be '3S LSS' where 3S means 'Simple, Speedy and Smart'. The new directions of the '3S' are summarized in Figure 4 together with their innovation enablers. For the simple LSS, we need an easy problem-solving roadmap, and simple and open procedures. Use of traditional easy tools of Six Sigma and Lean such as DMAIC phases, project team activities of green belts and black belts, value stream mapping, 5S (Sort, Set in order, Shine, Standardize and Sustain), etc. Also simple statistical modelling for prediction is much simpler by using statistical software such as R, SAS, Minitab and so on.

We can observe that the speed itself has become an important characteristic of Quality Management which we believe will be even more important in the future. To achieve speedy LSS, speedy on-site improvements based on 'Open Data' will be necessary. Also project activities should provide speedy improvement in short time. The use of new methodologies such as Big Data, AI and IoT will be introduced, and some type of business customer platforms will be extensively practiced.

For the ***smart*** LSS, mass customized 'Smart Factory' methods for business improvement will be adopted, and LSS associated with smart 'green' initiatives will be introduced. Also AI and Big Data assisted LSS activities for quick and correct action will be used.

There are many 3S LSS innovation enablers, and some of them are listed in Figure 4. The first one is 'IT based open quality system for speedy multi-way information flow', which emphasizes that the open, speedy and multi-way simultaneous information (quality, productivity, customer demand, waste, value stream, etc.) flow among all stages (plan, design, production, marketing, sales, etc.) of company business is an important 3S LSS innovation enabler. The lastly listed one is 'intensive use of the 4th IR technologies such as Big Data, AI and IoT'.

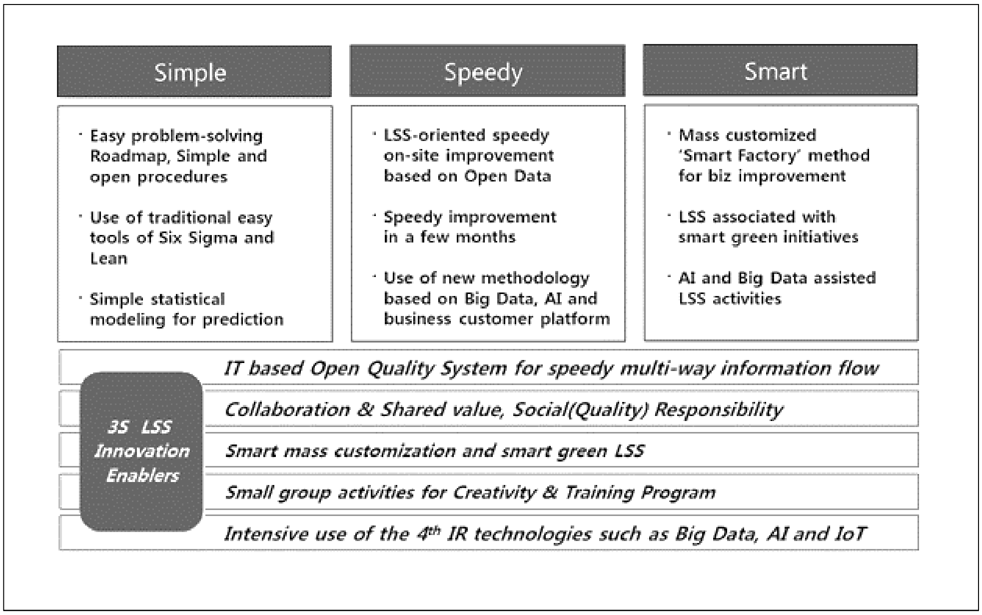


Figure 4 – The Four Stages of IR, Production Strategy, Quality Goal and Quality Strategy

In the 1990s the internet technology was the most powerful in changing the society. It seems that in the 4th IR, AI will become the most powerful technology to change almost everything including the industry. For instance, AI in a hospital can read several thousand MRI pictures in a few minutes, and can diagnose the patients much better than the doctors. There are at the moment no limits for the number of possible AI related LSS projects which LSS may handle and many countries have announced new intended or already initiated AI initiatives. In USA for example, the Trump administration has announced that the most important technology in a generation is AI, and announced the Executive Order on 'Maintaining American Leadership in AI' (issued on February 11, 2019).

Table 2 – The Simple Approach for the DMAIC Process in the New Paradigm of Lean Six Sigma

Phases	**Standard 15 steps in the past LSS**	**Simplified 5 steps for '3S LSS'**
Define	1. Project selection 2. Project definition 3. Project approval	1. Problem definition
Measure	4. Confirm Y's 5. Confirm Baseline of Y's 6. Confirm potential causes(X's)	2. Goal setting and confirmation of Y's and X's
Analyse	7. Collect data 8. Analyse data 9. Select vital few X's	3. Analysis of data and selection of true causes

Phases	Standard 15 steps in the past LSS	Simplified 5 steps for '3S LSS'
Improve	10. Establish improvement plan 11. Optimize vital few X's 12. Validate improved results	4. Optimization and Improvement
Control	13. Establish control plan 14. Execute control plan 15. Documentation	5. Standardization and control plan

As an example of simple LSS, we propose an easy problem-solving roadmap for DMAIC to be used in all business areas. In the past the standard of 15 steps have been used for the DMAIC process, but in the simple LSS much simpler 5 steps may be used as shown in Table 2.

Figure 5 shows another example of a 'simple, speedy and smart' manufacturing management process based on IT infra, in which LSS activities can work to reduce wastes and variability. Any LSS project team may work on this process to make the management simple and transparent, and to build speedy decision systems based on sound ethics and group innovation culture. In the process, several management systems are involved such as product data management (PDM), supplier relationship management (SRM), manufacturing execution system (MES), global logistics system (GLS), customer relationship management (CRM), advanced planning system (APS) and enterprise resources planning (ERP), and SCM.

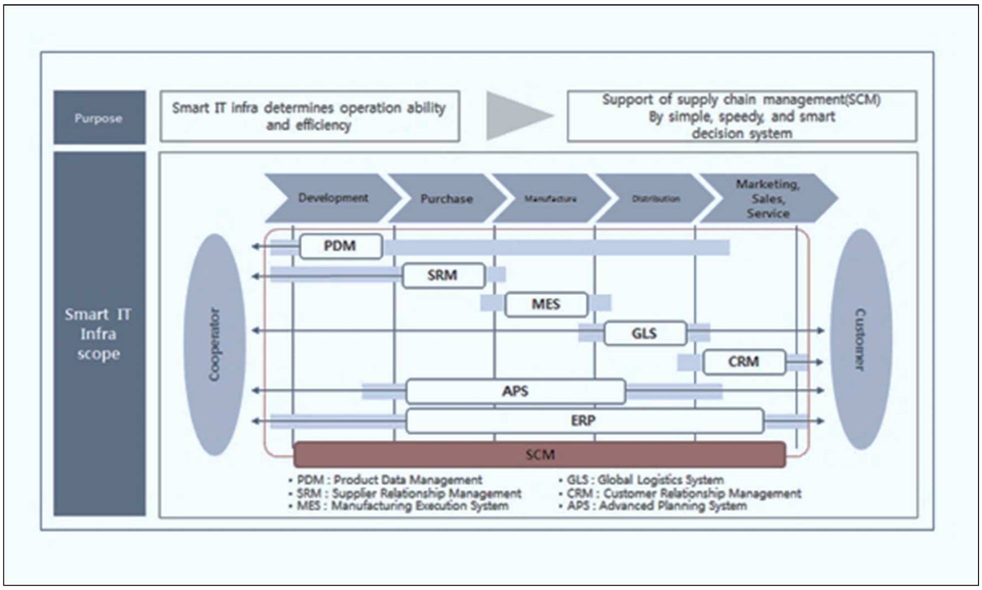


Figure 5 – An Example of Integrated Field Management Processes which 3S LSS Can Work on

4 A CASE STUDY OF 3S LSS IN KOREA

In this section the authors will shortly introduce a case study from Korea, where the 3S LSS concepts are practiced. Amore Pacific, which is the leading cosmetics company in Korea, started to implement Six Sigma in 2003 to "strengthen itself as a global company which satisfies the customers essential needs, and to attain a higher level of management capacity" (Amorepacific, 2020).

Kim and Ree (2017) explained that Amore Pacific introduced Lean manufacturing in 2016 to optimize not only process innovation with speed and waste reduction but also the ways to work for all business areas. The company combined Six Sigma with Lean and called the combined strategy 'Lean Sigma'.

Table 3 shows the ways of LSS implementation in Amore Pacific. The typical methodologies of Six Sigma, DMAIC and DFSS are modified to Lean concepts (Lean DMAIC, Lean DFSS, Lean Sales), and Lean QSS (Quick Six Sigma) is proposed and implemented by Amore Pacific. Table 3 also shows that the two concepts of 'speedy' and 'smart' are reflected in the 'Lean Sigma' framework. Amore Pacific also argues that it combines Six Sigma and Lean to make a simpler version of process management called 'Lean Sigma'. The company also declares that IT supported management makes Lean Sigma activities simpler than before. The authors found out, that the basic concepts of '3S LSS' are already been practiced in Amore Pacific, and Amore Pacific has achieved a big success in management innovation by using the new concept of LSS.

Table 3 – The new Concept of Lean Six Sigma in Amore Pacific

Business Area	**Lean Six Sigma (speedy and smart improvement)**				
	Lean DMAIC	Lean DFSS	Lean Sales	Lean QSS	Remarks
R&D	O	O			R&D process improvement New product development
Marketing (Sales)	O	O	O		New concept design for marketing and Lean-oriented sales services improvement
Manufacturing/Logistics	O	O		O	Lean-oriented on-site improvement in two-month
Management Support/IT	O	O			Lean-oriented 6 sigma improvement, and IRT supported smart management

5 IMPORTANT ASPECTS OF THE 3S LSS AS A NEW PARADIGM OF LEAN SIX SIGMA

Some of the important aspects of the new paradigm of LSS explained above are as follows.

(1) The important characteristics of the 4th IR such as mass customization, quality responsibility, open quality and smart factory will be incorporated into the 3S LSS. In practice it will be necessary for the 3S LSS activities to be simple, speedy and smart to match well to the characteristics of the 4th IR.

(2) The use of AI, Big Data and IoT will be more emphasized in the 3S LSS. Also the quality of data and software system will be of significant value.

(3) Corporate Social Responsibility (CSR) and Creating Shared Value (CSV) will become important concepts of the 3S LSS, and they will be combined to reflect quality responsibility.

(4) Speedy multi-way information flow for the 3S LSS activities will be more popular in all stages of production system (plan, design, production, marketing, sales) by use of IT, Big Data, AI and IoT.

(5) The 3S LSS experts will be more likely also data scientists in the future, because quality information can be mostly controlled by data analytics.

(6) Business platform companies will occupy more markets. The 3S LSS activities to improve the quality of platform will be more focused. AI platform software such as Google's 'AI Assistant' will be more powerful for business handling.

(7) Combining AI, Big Data, IoT and Cloud will begin to dominate the world market. The 3S LSS activities to improve the quality of such convergent technologies will be a major issue of quality management in the future.

To make the 3S LSS activities successful in the future, we need 9R success factors for the new paradigm LSS. They are as follows.

(1) Right style: Develop simple, speedy and smart style LSS which is suitable for the 4th IR.

(2) Right leadership: Get the top managers involved.

(3) Right participation: Keep the message simple and clear, and request the participation of all employees.

(4) Right project: Select the right projects and train capable black belts to concentrate on project team efforts.

(5) Right result: Focus on speedy (short-term) results and long-term growth.

(6) Right communication: Communicate, publicize and award results, and admit setbacks.

(7) Right link: Link customers and your processes.

(8) Right training: Make learning an ongoing activity, and make an investment to make it happen.

(9) Right tool: Use LSS tools wisely including Big Data, AI and IoT of the 4th IR technologies.

6 CONCLUSION

The 4th IR is changing the concept of QM as well as the concept of LSS. If a company is not well aware of the big change influenced by the 4th IR, the future prospect of its QM and LSS is not bright. It is suggested that the direction of the new paradigm of LSS will be ‘simple, speedy and smart’, which may be called the ‘3S LSS’ paradigm. Simple open procedures and simple statistical modelling will be mainly used. Speedy on-site improvement based on Open Data, and Big Data and AI assisted new methodology will be favoured. Also mass customized ‘Smart Factory’ method and LSS focused on smart green initiatives will be emphasized. For successful implementation of the new paradigm of LSS, 9R success factors are suggested.

The promotion of Six Sigma, Lean or Lean Six Sigma all over the world has been stabilized, and is somewhat decreasing. It is the authors’ belief that LSS quality initiatives and practices need to be changed to accommodate the trend of the 4th IR. It is our hope that this article may give some valuable insights to many quality experts for quality and innovation management promotion in this rapidly changing society. Also, since we are in the beginning stage of the 4th IR, there are not many research papers which study the impact of this revolution to QM and LSS. The authors expect that the near future will bring many challenging issues for the new directions of QM as well as LSS.

REFERENCES

Amore Pacific, 2020. Amorepacific at a Glace. [online] Available at: <https://www.apgroup.com/int/en/index.html> [Accessed on 20 March 2020].

Andersson, R., Eriksson, H. and Torstensson, H., 2006. Similarities and differences between TQM, Six Sigma and Lean. *The TQM Magazine*, [e-journal] 18(3), pp.282-296. DOI: 10.1108/09544780610660004.

Arnheiter, E.D. and Maleyeff, J., 2005. The integration of lean management and Six Sigma. *The TQM Magazine*, [e-journal] 17(1), pp.5-18. DOI: 10.1108/09544780510573020.

Bendell, T., 2006. A review and comparison of Six Sigma and the lean organizations. *The TQM Magazine*, [e-journal] 18(3), pp.255-262. DOI: 10.1108/09544780610659989.

Bhamu, J. and Sangwan, K.S., 2014. Lean manufacturing: literature review and research issues. *International Journal of Operations and Production Management*, [e-journal] 34(7), pp.876-940. DOI: 10.1108/IJOPM-08-2012-0315.

Cameron, D., 2014. CeBIT 2014: David Cameron's Speech. *GOV.UK*, [online] 9 March 2014. Available at: <www.gov.uk/government/speeches/cebit-2014-david-cameron-speech> [Accessed on 20 March 2020].

Chesbrough, H.W., 2003. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston: Harvard Business School Press.

Chesbrough, H.W., 2011. Bringing Open Innovation to Services. *MIT Sloan Management Review*, 52, pp.84-91.

Chesbrough, H.W., 2012. Open Innovation: Where We've Been and We're Going. *Research-Technology Management*, [e-journal] 55(4), pp.20-27. DOI: 10.5437/08956308X5504085.

Dahlgaard, J.J. and Dahlgaard-Park, S.M., 2006. Lean Production, Six Sigma Quality, TQM and Company Culture. *The TQM Magazine*, 18(3), pp.263-281.

Dahlgaard-Park, S.M., Chen, C.K., Jang, J.Y. and Dahlgaard, J.J., 2013. Diagnosing and Prognosticating the Quality Movement - a Review on the 25 Years Quality Literature (1987-2011). *TQM and Business Excellence*, 24(1), pp.1-18. DOI: 10.1080/14783363.2012.756749.

George, M.L., 2002. *Lean Six Sigma: Combining Six Sigma Quality with Lean Speed.* New York: McGraw-Hill.

George, M.O., 2010. *The Lean Six Sigma Guide to Doing More with Less Cut Costs, Reduce Waste and Lower Your Overhead.* New Jersey: John Wiley & Sons.

Harry, M.J., 1998. *The Vision of Six Sigma, 8 volumes*. Phoenix, AZ: TriStar Publishing.

Hoerl, R.W. and Gardner, M.M., 2010. Lean Six Sigma, creativity, and innovation. *International Journal of Lean Six Sigma*, [e-journal] 1(1), pp.30-38. DOI: 10.1108/20401461011033149.

Jasti, N.V.K. and Kodali, R., 2015. Lean production: literature review and trends. *International Journal of Production Research*, [e-journal] 53(3), pp.867-885. DOI: 10.1080/00207543.2014.937508.

Jugulum, R. and Samuel, P., 2008. *Design for Lean Six Sigma: A Holistic Approach to Design and Innovation*. New Jersey: John Wiley & Sons.

Kim, D.C. and Ree, S.B., 2017. A Study on Six Sigma – Past, Present and Future. In: ANQ (Asian Network for Quality), *Proceedings of 15th Asian Network for Quality Congress 2017.* Kathmandu, Nepal, 20-21 September 2017.

Krafcik, J., 1988. The triumph of the lean production system. *Sloan Management Review*, 30(1), pp.41-52.

Maistry, K., Hurreeram, D. and Ramessur, V., 2017. Total quality management and innovation. *International Journal of Quality & Reliability Management*, [e-journal] 34(3), pp.418-437. DOI: 10.1108/IJQRM-04-2015-0061.

Nave, D., 2002. How to compare Six Sigma, lean and the theory of constraints. *Quality Progress*, 5(3), pp.73-79.

Ohno, T., 1978. *Toyota Seisan Hoshiki* (Original Japanese edition). New York: Productivity Press.

Pacheco, D., Pergher, I., Vaccaro, G., Jung, C. and Ten Caten, C., 2015. 18 comparative aspects between Lean and Six Sigma. *International Journal of Lean Six Sigma*, 6(2), pp.161-175.

Park, S.H., 2003. *Six Sigma for Quality and Productivity Promotion.* Tokyo: Asian Productivity Organization.

Park, S.H. and Antony, J., 2008. Robust Design for Quality Engineering and Six Sigma. Singapore: World Scientific.

Park, S.H., Shin, W.S., Park, Y.H. and Lee Y.J., 2017. Building a new culture for quality management in the era of the 4th industrial revolution. The TQM & Business Excellence, [e-journal] 28(9-10), pp.934-945. DOI: 10.1080/14783363.2017.1310703.

Psomas. E. and Antony, J., 2019. Research gaps in lean manufacturing: a systematic literature review. *International Journal of Quality & Reliability Management*, [e-journal] 36(5), pp.815-839. DOI: 10.1108/IJQRM-12-2017-0260.

Pyzdek, T., 2001. *The Six Sigma Handbook: A Complete Guide for Greenbelts.* McGraw-Hill, New York: Blackbelts, & Managers at All Levels.

Schwab, K., 2015. The Fourth Industrial Revolution: What it means and how to respond. *Foreign Affairs*, [online] 12 December 2015. Available at: <https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution> [Accessed on 20 March 2020].

Singh, P. and Smith, A., 2004. Relationship between TQM and innovation: an empirical study. *Journal of Manufacturing Technology Management*, [e-journal] 15(5), pp.394-401. DOI: 10.1108/17410380410540381.

Sony, M., Antony, J., Park, S. and Mutingi, M., 2019. Key criticisms of Six Sigma: a systematic literature review. *IEEE Transactions on Engineering Management*, pp.1-13.

Van de Vrande, V., De Jong, J.P.J., Vanhaverbeke, W. and De Rochemont, M., 2009. Open innovation in SMEs: Trends, motives and management challenges, *Technovation*, [e-journal] 29(6-7), pp.423-437. DOI: 10.1016/j.technovation.2008.10.001.

West, J. and Gallagher, S., 2006. Challenges of open innovation: the paradox of firm investment in open-source software. *R&D Management*, [e-journal] 36(3), pp.319-331. DOI: 10.1111/j.1467-9310.2006.00436.x.

Wheat, B., Mills, C. and Carnell, M., 2001. The Path to Integration of Lean Enterprise and Six Sigma. Boulder City, Colorado: Publishing Partners.

Womack, J.P. and Jones, D.T., 2003. *Lean Thinking*. New York: Free Press.

Womack, J.P., Jones, D.T. and Roos, D., 1990. *The Machine That Changed the World: The Story of Lean Production.* New York: Rawson Associates.

ABOUT AUTHORS

Sung Hyun Park – (S.H.P.) Social Responsibility and Management Quality Institute, Seoul, Korea, Former President of Korean Academy of Science and Technology, Emeritus Professor of Seoul National University, e-mail: parksh@snu.ac.kr, Author's ORCID: 0000-0002-8683-7623.

Su Mi Dahlggard-Park – (S.M.D.-P.) Lund University, Sweden, Institute of Service Management, Professor, e-mail: sumi.park@msm.lu.se.

Dong-Chun Kim – (D.-CH.K) Hanyang University, Seoul, Korea, Center for Innovation in Engineering Education, College of Engineering, Adjunct Professor, e-mail: dongjunkim@hanyang.ac.kr.

AUTHOR CONTRIBUTIONS

S.H.P. – preparation of the first draft paper; S.M.D.-P. – reading the draft paper and revising the draft paper; D.-CH.K – preparation of all figures.

CONFLICTS OF INTEREST

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

The New EFQM Model: What is Really New and Could Be Considered as a Suitable Tool with Respect to Quality 4.0 Concept?

DOI: 10.12776/QIP.V24I1.1415

Jaroslav Nenadál

Received: 2020-03-05 Accepted: 2020-03-11 Published: 2020-03-31

ABSTRACT

Purpose: The paper offers a set of original information based on critical analysis of description two last versions of excellence models presented by the European Organisation for Quality Management (EFQM). The principle goal is to present the main advantages and weaknesses of the latest version of The EFQM Model, especially from a practical point of view with respect to a Quality 4.0 era.

Methodology/Approach: Comparative analysis of two relevant documents (EFQM, 2012; EFQM, 2019a) was used as a key method. Discussions with 18 quality professionals from Czech production organisations served as a complementary approach.

Findings: The basic structure of a new model was completely changed. But the description of certain recommendations by way of guidance points are superficial and confusing. It lays stress on the necessity to transform organisations for the future as well as on comprehensive feedback from key stakeholders.

Research Limitation/implication: The latest version of The EFQM Model was published in November 2019, and general knowledge related to this version is naturally limited. Published studies or publicly available experience completely absent. That is why a more in-depth literature review focused on the latest version of The EFQM Model could not be included in this text.

Originality/Value of paper: The paper brings an original set of information that was not published yet before. The value of this set should be examined not only from theoretical but primarily from a practical viewpoint.

Category: Viewpoint

Keywords: excellence; EFQM model; Quality 4.0; feedback; organisation

1 INTRODUCTION

Nowadays, the most of organisations throughout the world must strive to be more and more competitive. In some ways, the TQM philosophy is really recognised as an inspiring idea which supports this effort. So called Business Excellence Models (BEMs) have arose as efficient tools in this field more than 30 years ago (let me remind only the first version of The European Model for TQM established by EFQM in 1991). So called "organisational excellence" concept is very frequently discussed nowadays. American Society for Quality (ASQ, 2015) defines the term "organisational excellence" as ongoing efforts to establish an internal framework of standards and processes intended to engage and motivate employees to deliver products and services that fulfil customer requirements within business expectations". M. Webster (2016) argues that "organisational excellence is delivering, and sustaining the delivery of, outstanding value to all key stakeholders". And according to experts from EFQM: "Excellent organisations are those that achieve and sustain outstanding levels of performance that meet or exceed the expectations of all their stakeholders" (EFQM, 2012). Anyway, excellent organisations have some facets as sustainability, profitability, social responsibility, reputation and good governance. Some other features of the excellent organisations have been already described by Nenadál, Vykydal and Waloszek (2018) for example.

In Europe, The EFQM Excellence Model is the most known and implemented version of BEMs throughout the years. The original version of The European Model for TQM was upgraded by repeatedly way and next-to-last version from 2012 (EFQM, 2012) was fully accepted by management community (not only in Europe!) as the most advanced tool for achieving a long term success and excellent level of an organisational performance. The latest version of this model has been designed from years of experience in changing markets to understand the benefits of organisational analysis, future forecasting and predictive intelligence in driving true transformation. It was launched in November 2019 to replace version from 2012.

2 RESULTS AND FINDINGS

Following results and findings were obtained on basis of comparative analysis of two relevant documents (EFQM, 2012; EFQM, 2019a) describing concepts, frameworks and criteria included into last two versions of the model. Presented results and findings will cover four areas of interest that follow.

2.1 Official Title of the Model

Version 2012: The EFQM Excellence Model.

Version 2020: The EFQM Model.

Omitting the word "Excellence" at the model's version 2020 can not be evaluated as positive item! After all, from core semantic perspective: any model must be a model of something and the new title could be nothing to say and confusing for a lot of managers without relevant quality background!

2.2 Overall Model Structure

The EFQM Excellence Model (EFQM, 2012) has comprised three integrated components:

- The Fundamental concepts of Excellence. They were about eight core principles of organisational excellence: adding value for customers, creating a sustainable future, developing organisational capability, harnessing creativity and innovation, leading with vision, inspiration and integrity, managing with agility, succeeding through the talent of people, sustaining outstanding results.
- The Criteria as a framework to help organisations convert fundamental concepts into practice (9 main and 32 partial criteria were included into this framework).
- The RADAR logic as dynamic assessment framework that allows to calculate overall organisational excellence level (maturity) through pointing and discovering areas for next improvement of the management system.

On the contrary, The EFQM Model (EFQM, 2019a) does not comprise concepts of excellence explicitly, but they are hidden and integrated into all new sections of the model. The RADAR logic is mostly kept there in original way, also as natural part of the model. Such simplification of overall model's structure wants all managers to perceive as beneficial feature with regard to its practical implementation.

2.3 Framework of the Criteria

Let us suppose a framework of criteria, so typical for previous The EFQM Excellence Model is commonly known (see EFQM, 2012; Oakland, 2014; Kanji, 2015) and many others. In comparison, the new model is based on completely changed framework. Now, it consists from three key sections:

- Direction (Why do it?);
- Execution (How do it?);
- Results (What is achieved?).

See Figure 1, the logical linkages among these three sections are evident and they seem to be easy to understand for all, who are engaged in practical development of management systems.

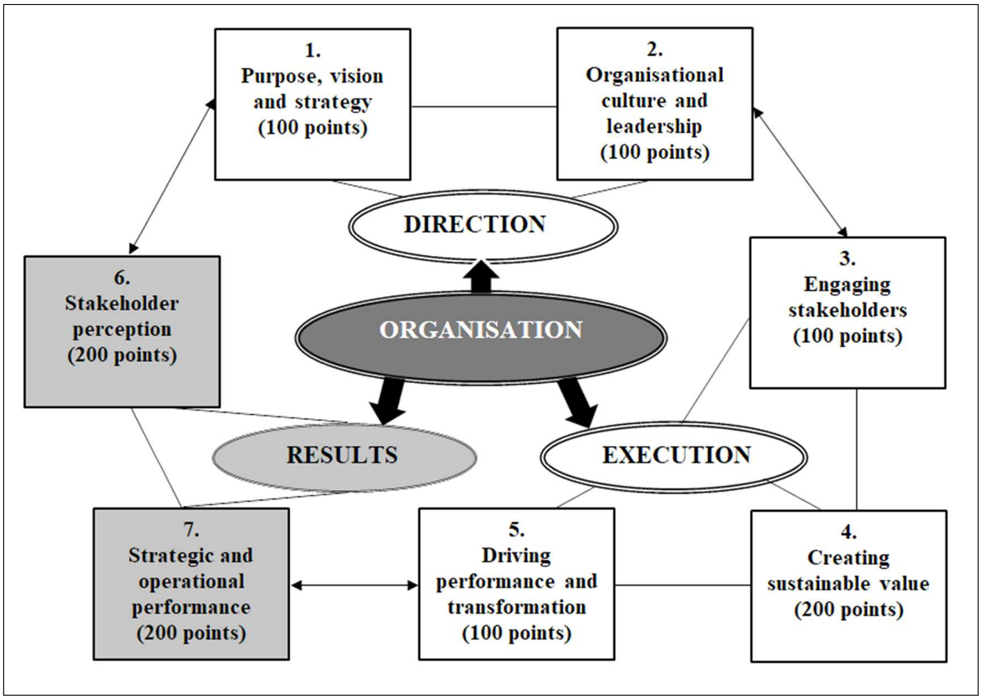


Figure 1 – Structure of the EFQM Model (Adapted According to EFQM, 2019a)

Instead nine main criteria which created framework of previous The EFQM Excellence Model, the new model is inclusive of seven main criteria:

1. Purpose, vision and strategy (5 partial criteria are included in this criterion);
2. Organisational culture and leadership (4 partial criteria are included in this criterion);
3. Engaging stakeholders (5 partial criteria are included in this criterion);
4. Creating sustainable value (4 partial criteria are included in this criterion);
5. Driving performance and transformation (5 partial criteria are included in this criterion);
6. Stakeholder perception (there is no partial criterion);
7. Strategic and operational performance (there is no partial criterion).

Their matching with key sections is visible from Figure 1. Pointing identifies importance of each main criterion. Total amount of poins (1,000 p.) is the same as when scoring organisation’s maturity (through self-assessment or external assessing) against The EFQM Excellence Model, version 2012.

In addition, the interactions of the strategic nature of the model (presented by criteria 1 and 2) and operational performance (criteria 3 – 5) or all organisation’s results (criteria 6 and 7) represent really remarkable feature that is more evident when compare the previous version of the excellence model. Cause and effect links are much more visible in the new model and it could contribute to the wider acceptance by all levels of managers and academics. Another impressive change bears on the term “sustainable value”. It replaces such words as “product” or “service” predominantly. In spite of the “sustainable value” could be less tangible for very practitioners, this term is more generic and underlines necessity to produce and deliver outputs that bring the real value not only for customers but also for another interested parties. And the last logical and positive change: all results regarding to the stakeholders perception (and obtained through effective feedback) are concentrated into one main criterion 6 now. That is remarkably different from the previous The EFQM Excellence Model, where such results were scattered into three different result criteria.

2.4 Criteria Description through Guidance Points

From practical viewpoint, a set of so called “guidance points” represents certainly the most important part of each version of EFQM descriptive documents. This set has been developed as a result of the best practice sharing and it was recognised as an inspiring know-how related to each partial criterion of the model. And to tell the truth, the main weaknesses of The EFQM Model, version 2020 are hidden right there! Now, on basis of my personal investigation I would like to call attention only to some of them:

- A quite new term “ecosystem” occurs repeatedly within some guidance points. This term is explained as: “fundamental principle of an ecosystem is interdependence, i.e. something that happens in one part of the system may affect other parts within the system. In the context of the organisation there are many factors external to it that affect how it operates”. See chapter Glossary at (EFQM, 2019a). What does it mean? It is obvious the term “ecosystem” is not considered from environmental point of view at all! It is used for external issues of the context of the organisation in sense of ISO 9001 standard (ISO, 2015). And it stands to reason, this could be rather confusing matter in practice!
- A serious recommendation oriented to designing and implementation of a performance management system can be found within criterion 1 of The EFQM Model now. It seems to be nice and rational but some managers could draw the line between an overall management system and the performance management system – what is nonsense of course.
- Comparing the previous version of the model, the latest version underestimates a comprehensive approach to the human resources management. For example, there are no recommendations related to: defining the skills, competencies and people performance level, inspiring people participation of activities that are beneficial for wider society, a teamwork promotion, etc.

- The guidance points are frequently described only in general, what could be hardly to understand by practitioners. Many wordings are all but tangible. A following formulation included into description of the partial criterion 4.4 (titled as Define and Implement the Overall Experience) should serve as an example: "An outstanding organisation takes advantage and opportunities to personalise the overall experience for its target groups, as well as the specific products, services and solutions" (EFQM, 2019a).
- At The EFQM Model, version 2020 is no recommendation leading to measuring and optimising the impact of organisation's operations, product lifecycle and services on public health, safety and the environment. The organisation's role in area of social responsibility moves downwords in reality.
- An accent on framework of key processes using for efficient organisation's strategy implementation is also missing, as well as underlining the role of a process owners, which can lead to underestimating of a process approach as a basis for any management system development and improvement.
- The necessity of benchmarking activities focused especially on performance indicators is visibly repressed at the guidance points of the latest version of the model, even though benchmarking is still mentioned as one pillar of The RADAR logic.
- Unlike The EFQM Excellence Model (EFQM, 2012), any recommended shortlist of suitable indicators completely absents at The EFQM Model (EFQM, 2019a) within description of new results criteria 6 and 7. We can read only about general areas (as a delivery of overall customer experience, a social and environmental responsibility, an achieving gender balance, a partners experience of dealing with the organisation, a financial performance, an achievements in driving transformation, etc.).

Apart from weaknesses mentioned above, we can discover many other shortcomings mostly tied to difficult understanding of various formulations, missing definitions of terms etc.

But on the contrary, when reviewing a new set of the guidance points, we are able to register also some positive changes in comparison to The EFQM Excellence Model (EFQM, 2012). The list of the most interesting and useful items follows:

(+) Probably, the most important change is associated with a support and providing creativity and innovation. Minimally 8 different guidance points related to the creativity and innovations are newly concentrated into special partial criteria 2.3 and 5.3 as a response on fact that a lot of a European companies have got into the slow lane in this area.

(+) Other underlined relationships bear on so called business and governing stakeholders as investors, funding organisations, regional bodies, public authorities etc. An outstanding organisations should make sure such relationships are mutually beneficial.

(+) What differentiates the organisation from others, including competitors, this should be recognised and communicated as a natural part of values delivered to various stakeholders, including customers and partners.

(+) Certain recommendations related to the risks identification, analysis, evaluation and treatment go beyond mere financial risks at the latest version of The EFQM Model. Now, the risk management should cover all categories of risks, including legal, societal, cyber security, etc.

(+) An asset management should reflect a Circular economy principles in case a certain infrastructure must be disposed.

3 THE EFQM MODEL, VERSION 2020 AND THE QUALITY 4.0 CONCEPT

We are able to notice also another two remarkable changes by way of quite new items among all guidance points in the latest version of The EFQM Model:

(+) Partial criterion 5.2 is strongly oriented to necessity to transform current organisation for the future.

(+) Main criterion 6 (Stakeholders perception) is fully based on a comprehensive feedback from key stakeholders. Their perceptions should be obtained from number of sources, including social media, advocacy, etc.

These recommendations ought to be seen as a nice challenge faced the Quality 4.0 concept, especially in area of B2B relations.

Quality 4.0 is an immediate reference to Industry 4.0. Unfortunately, none serious articles can be referred in this area at present. This topic is too fresh and therefore the discussions and information sharing are mostly held through Internet blogs, for example Jacob (2017a), Kőpper et al. (2019), Rigert and Writer (2020). The most valuable studies in area of Quality 4.0 are probably performed by LNS Research Company. According its investigations, the most of industrial companies will have to be transformed towards Industry 4.0 during next five years, including quality management conversion (Jacob, 2017b). When study these sources, we can identify following features of the Quality 4.0 concept:

- This term comes from Industry 4.0 and it covers all issues of an advanced quality management at digital era.

ISSN 1335-1745 (print) ISSN 1338-984X (online)

- It is not closed-ended term. It should be seen as a certain umbrella term, that openly describes a new-data driven approach to manage of all quality requirements.
- Four main areas to address by Quality 4.0 are frequently stressed: design and development, production, service and company culture. Especially, the last item must be recognised at our environment – see Zgodavova, Hudec and Palfy (2017) for more details.
- A special attention is paid to the methods and tools enabling agile B2C communication and efficient feedback.
- An extensive IT support is crucial precondition for Quality 4.0 practical establishing.
- A reliable and quick connectivity as well as interaction among machines, people, organisational units and stakeholders are not aim, these connections are looked upon a means for effective and efficient quality improvement and innovations.
- The Quality 4.0 effectively blends new technologies (cloud computing, big data, artificial intelligence, machine learning, Internet of things, etc.) with proved quality management methods and tools.
- The TQM philosophy (including active participation of all staff) is respected as a natural part of Quality 4.0.
- A transformation from traditional quality management to the Quality 4.0 concept will take huge financial resources, people knowledge and time too.
- So called "Closed-Loop Quality Management Systems" are generally considered as suitable basis for sequential implementation of the Quality 4.0 concept, not only within B2B area.

The last item deserves some additional remarks. K. Sundaram (2018) argues the organisations belief that traditional quality management systems are increasingly making a move towards the more future-ready and a closed-loop approach is expressed there. Goulévitch (2018) lists eight examples of how the closed-loop quality management systems should function, including transparency in production processes, traceability, integrating with information systems, facilitating Lean processes, etc.. Lim (2020) underlines that the Quality 4.0 and the closed-loop quality management enable to transform the conventional quality management in real time. Since an exact definition of the closed-loop quality management system is not available till the time, let me see it as a natural part of the overall organisation's management system based on advanced quality management principles that enables to connect all quality management processes and performance data with aim to improve the organisational quality and achieve the organisational excellence. The closed-loop quality management systems should be created and developed as a comprehensive mixture of an internal, external, horizontal and vertical loops. These loops must naturally:

- cover all organisational levels, from strategic to shop floor,
- connect the organisation with all key stakeholders, not only with customers,
- be tailored according specific organisational environment and should represent a unique set of processes,
- be based on agile feedback loops in advance.

At present, such quality management systems are in progress, especially at automotive industry. But when we use the Industry 4.0 Maturity Index perspective, distinguishing six stages in the Industry 4.0 development, such as computerisation, connectivity, visibility, transparency, predictive capacity and adaptability – (see Shuh et al., 2017), such effort is mostly at the beginning.

4 CONCLUSION

The organisational excellence cannot be considered as overcomplicated matter. On the contrary, it must be seen as a nice opportunity for sustainable business success! Therefore, various excellence models are expected to play a crucial role at this effort. According to our investigations and when consulting the latest version of The EFQM Model, we are able now to declare some final remarks concerning possible implementation of this model with respect for current trends covered by the Quality 4.0 concept:

a) The EFQM Model will stay a very advanced and generic tool for any organisation striving to be successful on the excellence journey.

b) Huge group of creators (nearly 2000 change experts and leaders from 60 diverse organisations (EFQM, 2019b; EFQM, 2019a)) had original aim: to shift the new model from being only assessment tool to one that offers a vital framework and methodology to help with changes and transformation. Under my opinion, this goal was achieved only partially.

c) Basic structure of The EFQM Model was completely changed (see Fig. 1). The arrangement, which covers three key sections and seven main criteria, is undoubtebly a positive and radical shifting – it is more logical and simplier in comparison to The EFQM Excellence model, version 2012. But this advantage is called into question through following shortcomings:

d) Some terms used there are unclear, defined by inproper way only (or not defined at all) what can cause a confusion for a lot of practitioners and make troubles within the model implementation.

e) The description of many guidance points is superficial only, ambiguous and less concrete.

f) Some important recommendations absent completely within sections Direction or Execution, for example in area of the human resources management, the process approach establishing, etc.

g) Any recommended set of suitable performance indicators is absolutely missing in section Results.

h) A long-term orientation to the Quality 4.0 concept is not mentioned by explicit manner at The EFQM Model, it is slightly hidden, but it is incorporated through stressing a necessity to transform current organisations for the future as well as on a comprehensive feedback from key stakeholders. The closed-loop quality management systems can be seen as efficient contribution to such transformation.

Briefly to say: the latest version of The EFQM Model is not better or worse in comparison to the version from 2012. Simply expressed: it is else one. Advantages and weaknesses are mutually balanced there and only a near future will show if this model is valuable tool for digital transformation of the organisations and their management systems. While the previous versions of excellence models were matter of people engagement, education, training and motivation in advance, a combination of the organisational excellence and the Quality 4.0 concept will require also considerably investments and a quite new work position development. Anyway, a huge challenge occurs in front of us!

ACKNOWLEDGEMENTS

This work was supported by the European Regional Development Fund under grant "A research Platform Focused on Industry 4.0 and Robotics in the Ostrava Agglomeration", project No. CZ.02.1.01/0.0/0.0/17_049/000845 and VŠB-Technical University of Ostrava under grant No. SP 2020/51 "Development of selected areas of modern quality management systems with respect to Quality 4.0 concept".

REFERENCES

American Society for Quality (ASQ), 2015. *What is Organizational Excellence?*. [online] Available at: <https://asq.org/quality-resources/organizational-excellence> [Accessed 12 February 2020].

EFQM, 2012. *EFQM Excellence Model 2013*. Brussels: EFQM Representative Office.

EFQM, 2019a. *The EFQM Model*. Brussels: EFQM.

EFQM, 2019b. *How is the EFQM Model 2020 development doing?*. [online] Available at: <https://www.efqm.org/index.php/2019/05/10/how-is-the-efqm-model-2020-development-doing/> [Accessed 12 February 2020].

Goulévitch, V., 2018. *Eight examples of properly working closed-loop quality system.* [online] Available at: <https://www.controleng.com/articles/eight-examples-of-a-properly-working-closed-loop-quality-system/> [Accessed 13 November 2018].

ISO, 2015. *ISO 9001 Quality management systems - Requirements*. Geneve: ISO.

Jacob, D., 2017a. *What is Quality 4.0.*. [online] Available at: <www.juran.com/blog/quality-4-0-the-future-of-quality> [Accessed 14 January 2019].

Jacob, D., 2017b. *Quality 4.0 Impact and Strategy Handbook.* Cambrige: LNS Research.

Kanji, K.G., 2015. *Measuring Business Excellence*. New York: Routledge.

Kőpper, D., Knizek, C., Ryeson, D. and Noecker, J., 2019. *Quality 4.0 Takes More Than Technology.* [online] Available at: <www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology.aspx> [Accessed 7 January 2020].

Lim, J.S., 2020. *Quality Management in Engineering. A Scientific and Systematic Approach.* Boca Raton: CRC Press.

Nenadál, J., Vykydal, D. and Waloszek, D., 2018. Organizational Excellence: Approaches, Models and their use in Czech Organizations. *Quality Innovation Prosperity,* 22(2), pp.47-64. DOI: 10.12776/QIP.V2212.1129.

Oakland, J.S., 2014. *Total Quality Management and Operational Excellence. Text with Cases. Fourth Edition*. London: Routledge.

Rigert, M., Writer, S., 2020. *Why Quality 4.0 Should Be a Top Priority for Quality Managers*. [online] Available at: <www.mastercontrol.com/qxp-lifetime/the-quality-leaders-guide-to-quality-4.0/> [Accessed 19 January 2020].

Shuh, G., Anderl, R., Gausemaier, J., Hompel, M. and Wahlster, W., 2017. *Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies (acatech STUDY).* Munich: Herbert Utz Verlag.

Sundaram, K., 2018. *Quality in the Future of Manufacturing*. Santa Clara CA: Frost & Sullivan.

Webster, M., 2016. *So what is organizational excellence.* [online] Available at: <https://realorganisationalexcellence.com/2011/08/25/so-what-is-organisational-excellence/> [Accessed 12 December 2017].

Zgodavova, K., Hudec, O. and Palfy, P., 2017. Culture of quality: insight into foreign organisations in Slovakia. *Total Quality Management & Business Excellence*, 28(9-10), pp.1054-1075. DOI: 10.1080/14783363.2017.1309120.

ABOUT THE AUTHOR

Jaroslav Nenadál – VSB-Technical University of Ostrava, Czech Republic, Faculty of Materials Science and Technology, Department of Quality Management, Prof., e-mail: jaroslav.nenadal@vsb.cz, Author's ORCID: 0000-0003-1526-8694.

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.

The Role of Supplier Quality in e-Procurement Negotiation

DOI: 10.12776/QIP.V24I1.1388

Radoslav Delina, Mária Michňová, Peter Húska, Ján Spišák

Received: 2020-01-20 Accepted: 2020-02-27 Published: 2020-03-31

ABSTRACT

Purpose: The purpose of this study is to examine the significance and the role of supplier rating as a formalised supplier quality measure to achieve better-negotiated prices and to identify price premium resulting from improved rating.

Methodology/Approach: Data from real B2B environment of electronic reverse auction SW solution ProeBiz were obtained and processed. Data from the reverse rating approach were used where the default rating value is 1 and improvements of rating lead to decreasing the rating value. Except standard descriptive statistics, non-parametric correlation and Kruskal-Wallis tests, the knowledge discovery techniques by decision trees CHAID algorithm were used.

Findings: From our empirical research results, there is the evidence of a significant positive relation of supplier quality or rating improvements on a negotiated price for suppliers. Improving rating from the default value (1.00) to (0.98-0.95) can lead to better- negotiated prices for suppliers in English auction expressed as price premium in the value of 4%.

Research Limitation/implication: Research has several limitations, esp. in the size of the sample and sectorial view as the research is based on data from construction, electro-mechanics and logistics sector.

Originality/Value of paper: The paper is original and not published in other publications.

Category: Research paper

Keywords: rating; supplier quality; electronic reverse auction; price premium; e-procurement

1 INTRODUCTION

There is now a wide range of concepts and theories that analyse the economic aspect of trust in society. The importance of trust for society is being investigated by many sociologists, economists, political scientists and others. From the economic point of view, it is considered primarily as a factor that influences the dynamics and formation of economic processes, reduces transaction costs and eliminates barriers to cooperation.

Fukuayma (1995) discusses that differences in the economic performance of individual countries result from differences in their propensity to build trust-based relationships. Trust involves accepting the risk of interaction. If we perceive trust as intellectual property of an individual, its determinants are primarily the personal, value and emotional characteristics of the individual. On the other hand, "trust is perceived as systemic ownership of the company and its central institutions".

The importance of trust has been confirmed in researches from many scientific disciplines such as sociology, political science, economics, philosophy and in various areas of management. In management, trust is perceived as an important factor affecting communication, leadership, negotiation, working relationships, etc..

Knack and Zack (2003) discuss that "greater interpersonal confidence affects the decline in transaction costs associated with investment activities in the country, ultimately affecting economic growth".

The conclusions of many scientific papers on the study of trust and its position in the economy clearly show that "high-confidence companies have a higher rate of investment and growth".

On the basis of a summary of the above statements, we can assume that a high level of confidence in a country has a positive effect on the development of some macroeconomic indicators. Although the modern socio-economic approach to trust is often criticized because of the ambiguity of the conclusions, it is probably the most successful modern concept in economic theory in recent decades (Locke, 2001).

Many economists are currently discussing how to achieve an optimum level of confidence and thus stimulate its economic growth. However, several studies are shifting this issue into B2B relations and examining how trust in supplier quality can determine the economic performance of B2B relations and total corporate performance (Santos, Murmura and Bravi, 2019; AlMaian et al., 2016; Charki and Josserand, 2006). The purpose of the vendor rating is to manage, measure and improve the quality level of the supplier's performance.

Although many studies are focused on how to measure or apply rating systems to measure supplier quality, only a few are examining the following impact of this quality measurement values on negotiation results and vendor selection.

The diagram in Figure 1 illustrates the possible effects of trust on some key factors such as e.g. investment, human capital management, transaction costs, collective organization and collaboration, all of which determine economic prosperity and economic growth.

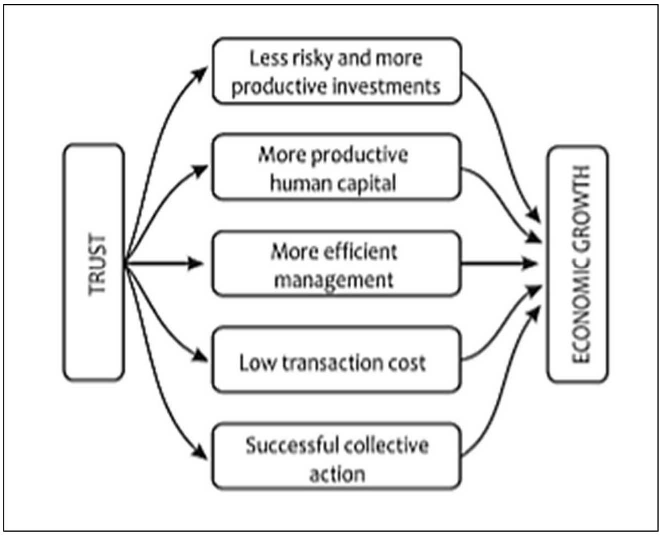


Figure 1 – Trust and Its Economic Importance (Lekovic, 2012)

2 IMPACT OF RATING AND TRANSPARENCY

The result of a transparent process is to build stable and healthy relationships with suppliers. However, in many cases, the use of e-auctions to select a supplier disrupts long-term relationships with current suppliers. There is the possibility of using e-auctions as a tool for researching the market prices of purchased goods and services. Buyers can use this information to negotiate with the current supplier about better purchasing conditions.

From this point of view, a company must consider how the change will have the influence – deterioration of relations with current suppliers.

It should be considered whether they are strategic or non-strategic suppliers, i.e. regular suppliers. It is not advisable to use e-auctions for strategic suppliers. Mainly, these are suppliers of critical and low-value goods and services. For non-strategic suppliers, however, the use of e-auctions is more than just a good choice. In such cases, the buyer’s power to negotiate is increasing, the supply markets are differentiated and allow the use of negotiation tactics (Schwarts, 2001). Such “tactical” and premeditated actions to abuse the other party result in worsened supplier-customer relations.

Beall et al. (2003) pointed to the paradox that more vendors than buyers believe in a deteriorated supplier-supplier relationship due to the use of e-auctions. In e-commerce, the established mechanism is a rating, which makes it possible to evaluate a partner's behaviour after a business transaction. The rating can thus be considered a mirror of distrust and reflection of past experience (Tsai and Chow, 2011; Dorčák, Pollák and Szabo, 2014; Szabo, 2015; Santos, Murmura and Bravi, 2019; AlMaian et al., 2016).

The rating system is based on the feedback that is given at the end of each completed transaction and tells the participant's behaviour during the transaction. All submitted evaluations are accumulated into one value, which serves to support decision-making in the selection of the final supplier. Delarocas (2006) argues that this is a feedback system in which information and experience are shared in order to limit future unfavourable choices. Most often it is a numerical rating or star rating, supplemented by a verbal description of the course of trade. At present, such an evaluation mechanism is (according to our information) implemented and used in the evaluation of e-auction in only a few companies.

The evaluation of suppliers has an impact in two main ways:

- The rating has a discriminatory effect, in that it helps to distinguish differences between suppliers and thus you would better avoid it.
- The rating has a predictive effect, in the sense that a rating that has already been received indicates that it will be successful in the future. Reputations very important information in two points of view. It:
  - assists the e-auction participant (advertiser, buyer) in the decision-making process among several sellers who have submitted relatively similar offers for the same product.
  - supports the process of eliminating occasional (negative) supplier behaviour which would be unprofitable in the long term as it would lead to the rating downgrade and discouraging business partners from future cooperation.

3 METHODOLOGY

The database used after modification contains 110 records from e-auctions which were realised mainly in the fields of construction, electrical material and transport services. All 110 records were realised by electronic reverse auction ERMMA with information of supplier rating.

The database is gathered from e-auction SW provider NAR Marketing, as the biggest central European company in this field. Although the data are much bigger, the samples with real rating usage were only in 110 procurements. It is interesting, that they are only from 3 sectors (esp. logistics).

The supplier rating is used for negotiation in an electronic reverse auction in the way, that the individual bids/prices of the bidders are multiplied by their rating value. It means, each supplier starts with rating 1 and in the case, the supplier is satisfied with the supplier, he will decrease the rating of supplier and vice versa.

The mechanism of rating implementation in electronic negotiation is set up in the way, that the price of supplier is multiplied by the rating and in this situation, the lower rating improves the final price and helps suppliers to get on higher ranks.

Table 1 – The Description of Research Sample

	N	Minimum	Maximum	Mean	Std. Deviation
Auction savings	112	-0.0110	0.4773	0.071880	.0965243
NoParticipants	112	1	16	8.74	2.955
WinnerRating	112	0.950	1.030	0.96393	0.023341
WinnerRatingPosition	112	0.986	1.026	1.00112	0.009007
AvgRating	112	0.95	1.01	0.9628	0.02079
MedianRating	112	0.95	1.01	0.9587	0.01929
Valid N (listwise)	112				

4 RESEARCH AND DISCUSSION

Within this study, we are examining the role of rating as one of the transparency settings on final auction performance measured by the winning contract at the negotiated price.

For this purpose, we have to analyse the relation between rating values against winning price reduction (auction savings). In our sample, we have two types of savings: total and auction saving. Total savings are calculated from multi-round negotiations, where the first round is still a market survey (using sealed bids). The best price is used as an input price for ERMMA negotiation in the second round.

For our analysis, on the base of attributes directly gathered from the database, we have also calculated derived attributes useful for our working question:

- *NoParticipants* – the number of participants involved in the procurement process;
- *Winnerbid* – the volume or price of the winner within the negotiation;
- *AllRatingsWinner* – the rating of the winner;
- *WinnerRatingPosition* – rating position within the interval of all participants' ratings calculated as *AllRatingsWinner/AvgRating*;
- *AvgRating* – average rating within all participants in a specific negotiation;
- *MedianRating* – the median of ratings of all participants in a specific negotiation.

As we see from the non-parametric correlation test using Spearmann in Table 2, almost all attributes were correlated with auction savings on a significant level. Only winner rating position is not relevant. The highest correlation from rating attributes is visible by the rating of the winner as the most generic, although the knowledge behind will be explained later.

Table 2 – The Correlation Matrix

		No Participants	*Winnerbid*	*All Ratings Winner*	*Winner Rating Position*	*Avg Rating*	*Median Rating*
Auction savings	Coeff	0.222	-0.403	0.363	0.142	0.392	0.273
	Sig.	0.020	0.000	0.000	0.140	0.000	0.004
NoParticipants	Coeff	1.000	0.150	0.123	-0.190	0.355	0.242
	Sig.	.	0.114	0.197	0.045	0.000	0.010
Winnerbid	Coeff		1.000	-0.259	-0.244	-0.173	-0.189
	Sig.		.	0.006	0.010	0.068	0.046
AllRatings Winner	Coeff			1.000	0.570	0.769	0.808
	Sig.			.	0.000	0.000	0.000
WinnerRating Position	Coeff				1.000	0.012	0.211
	Sig.				.	0.904	0.025
AvgRating	Coeff					1.000	0.661
	Sig.					.	0.000

As we have only 4 significant levels of ratings (the most negative 1.03 has only one winner in one procurement record) looking as an ordinal attribute we have applied non-parametric Kruskal-Wallis test to identify if there exist significant differences in statistical distributions against auction savings achieved. The result shows, that it is statistically significant on 0.03 level. When we are looking deeper in the descriptive statistics using boxplots, comparing winners' ratings with auction savings we can see, that the difference is quite clear and it provides the information that increasing winners rating leads to increased auction savings. It means, that to win the tender the supplier with a higher rating has to reduce his price significantly against suppliers with better rating values.

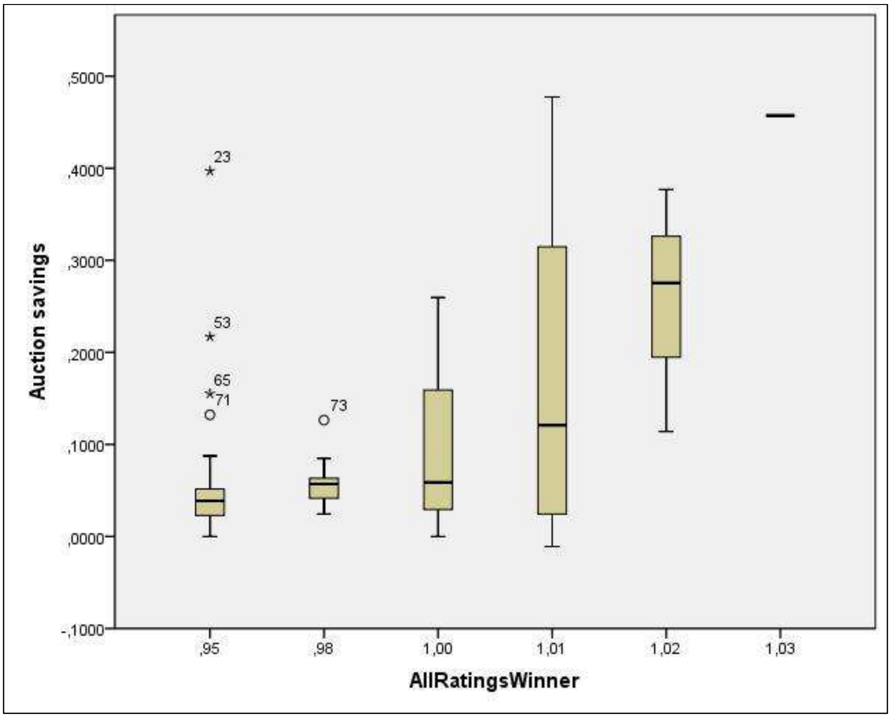


Figure – 1 Boxplot Analysis of Ratings vs. Savings

When comparing these results to the median of the whole sample which is 0.428, these statistics also provide additional information.

Table 3 – The Description of Research Sample

		Auction savings			
		Mean	Median	Mean total	Median total
AllRatingsWinner	0.95	0.0471	0.0388	0.719	0.428
	0.98	0.0585	0.0571	0.719	0.428
	1.00	0.1061	0.0587	0.719	0.428
	1.01	0.1822	0.1209	0.719	0.428
	1.02	0.2554	0.2753	0.719	0.428
	1.03	0.4572	0.4572	0.719	0.428

We can see, that the value of positive rating brings suppliers price premium, e.g. ratings on average 0.95 help the supplier to achieve on average 24.8% price premium or more realistically using median of 4% price premium. To support these results we were also using knowledge discovery techniques, esp. decision tree CHAID algorithm using entropy reduction approach for the classification of the most significant rules in the dataset. Results are presented in Figure 1.

ISSN 1335-1745 (print) ISSN 1338-984X (online)

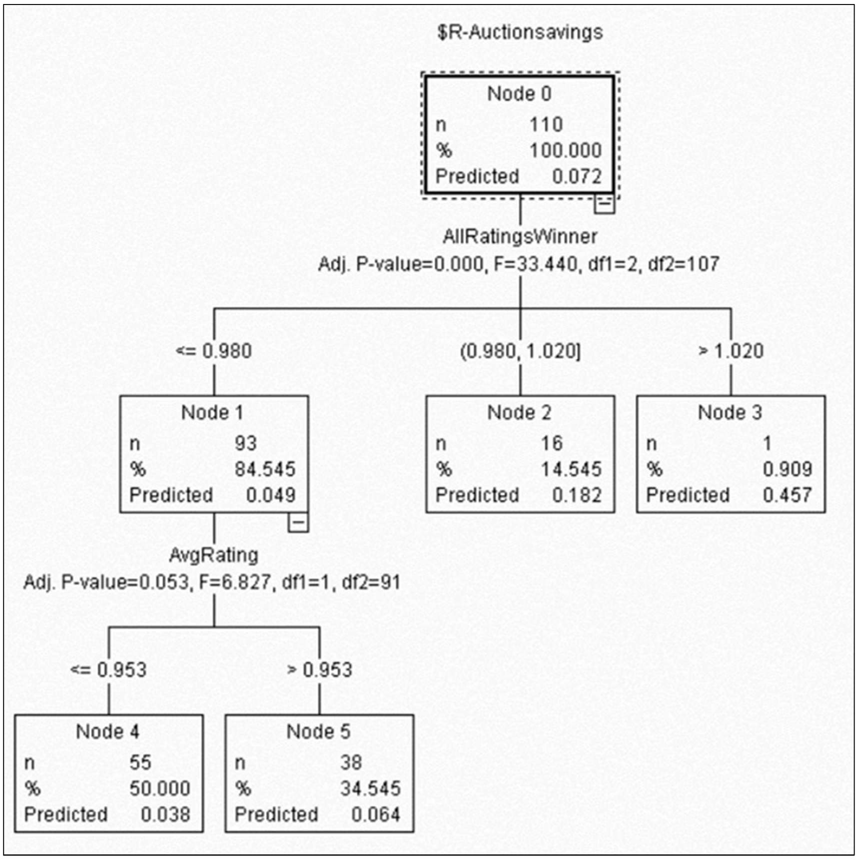


Figure 2 – Decision Tree (Rules) Results Using CHAID Algorithm

Using a decision tree or decision rules algorithm and interactive model by SPSS Clementine SW, the model presents the most significant decision rules on the significance of the rating related attributes with all inputs mentioned above. We see, that on the base of F-test, there are two significant basic clusters of rules (again, the third cluster is based only on one observation) where the most significant is the rating of the winner in two classifications. The simplified presentation should be stated as follows: in the case of a higher rating than one (default/neutral rating), the price premium rises to the value of 5%. Although in this sample there is also an interesting conditional rule that provides the information where the better average rating of suppliers within specific negotiation leads to an additional 1% premium.

5 CONCLUSION

This study was focused on empirical research into the role of ratings as a measure of supplier quality in B2B procurement negotiations based on data from real reverse auction environment in Slovak and Czech Republic.

Research results using also decision trees CHAID algorithm revealed significant importance of the supplier rating on the possibility to achieve price premium. From our analysis, we can formulate the conclusion, that improving rating can lead to 4% price premium for a supplier. This result shows the role of improved supplier quality and its potential to negotiate better contract condition.

ACKNOWLEDGEMENTS

This work was supported by the Slovak Research and Development Agency under Grant No. APVV-16-0368.

REFERENCES

AlMaian, R.Y., Needy, K.L., Alves, T.D.C. and Walsh, K.D., 2016. Analyzing effective supplier-quality-management practices using simple multiattribute rating technique and value-focused thinking. *Journal of Management in Engineering*, [e-journal] 32(1), 04015035, pp.1-13. DOI: 10.1061/(ASCE)ME.1943-5479.0000364.

Beall, S., Carter, C.R., Carter, P.L., Germer, T., Hendrick, T.E., Jap, S.D., Kaufmann, L., Maciejewski, D., Monczka, R.M. and Petersen, K., 2003. *The Role of Reverse Auctions in Strategic Sourcing*. Tempe, AZ: CAPS Research.

Charki, M. and Josserand, E., 2006. Does trust still matter in Business relationships based on online reverse auctions?. In: F. Feltz, B. Otjacques, A. Oberweis and N. Poussing, *AIM 2006 – Information Systems and Collaboration: State of the Art and Perspectives (AIM)*. Luxembourg, 8-9 June 2006. Bonn, Germany: Association information and management.

Dellarocas, C., 2006. Reputation mechanisms. In: T. Hendershott, ed., *Handbook on Information Systems and Economics*. Elsevier Publishing. pp.629-659.

Dorčák, P., Pollák, F. and Szabo, S., 2014. Analysis of the Possibilities of Improving an Online Reputation of Public Institutions. In: P. Doucek, G. Ch. and V. Oškrdal, *IDIMT-2014: Networking Societies - Cooperation and Conflict: 22nd Interdisciplinary Information Management Talks*. Poděbrady, Czech Republic, 10-12 September 2014. Linz: Trauner Verlag.

Fukuyama, F., 1995. *Trust: the social virtues and the creation of prosperity.* Free Press.

Lekovic, V., 2012. Trust as an Institutional Factor of Economic Success. *Economic Horizont,* [e-journal] 14(2), pp.65-78. DOI: 10.5937/ekonhor1202063L.

Locke, R.M., 2001. Building Trust. In: APSA (American Political Science Association), *Annual Meetings of the American Political Science Association.* San Francisco, California, 1 September 2001.

Santos, G., Murmura, F. and Bravi, L. 2019. Developing a model of vendor rating to manage quality in the supply chain. *International Journal of Quality and Service Sciences*, [e-journal] 11(1), pp.34-52. DOI: 10.1108/IJQSS-06-2017-0058.

Schwarts, R., 2001. *The electronic call auction: Market mechanism and trading: Building a better stock market: Too Much Transparency can be detrimental.* Springer Science + Business Media New York.

Szabo, S., 2015. Determinants of Supplier Selection in E-procurement Tenders. *Journal of Applied Economic Sciences*, 10(7(37)), p.1153-1159.

Tsai, K. and Chou, F., 2011. Developing a Fuzzy Multi-attribute Matching and Negotiation Mechanism for Sealed-bid Online Reverse Auctions. *Journal of Theoretical and Applied Electronic Commerce Research*, [e-journal] 6(3), pp.13-14. DOI: 10.4067/S0718-18762011000300007.

Knack, S. and Zack, P.J., 2003. *Building Trust: Public Policy, Interpersonal Trust, and Economic Development.* Supreme Court Economic Review, 10, pp.91-107.

ABOUT ABOUT AUTHORS

Radoslav Delina – (R.D.) Technical University of Kosice, Slovakia, Faculty of Economics, Department of Banking and Investment, Assoc. Prof., email: radoslav.delina@tuke.sk, Author's ORCID: 0000-0003-0412-9840.

Mária Michňová – (M.M.) University of Economics in Bratislava, Slovakia, Faculty of Business Economy, PhD student, e-mail: maria.michnova@student.euke.sk, Author's ORCID: 0000-0002-9954-6788.

Peter Húska – (P.H.) University of Economics in Bratislava, Slovakia, Faculty of Business Economy, PhD student, e-mail: peterhuska@icloud.com, Author's ORCID: 0000-0003-0674-082X.

Ján Spišák – Technical University of Kosice, Slovakia, Faculty of Mining, Ecology, Process Control and Geotechnologies, Assoc. Prof., e-mail: jan.spisak@tuke.sk, Author's ORCID: 0000-0002-2351-996X.

AUTHOR CONTRIBUTIONS

R.D. – concept, oversight, leadership, research activity planning, execution, design, methodology; M.M., P.H. and J.S. – formal analysis, manuscript writing.

CONFLICTS OF INTEREST

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

The Application of Internet of Things in Metering the Consumption of Utilities in the Czech Republic

DOI: 10.12776/QIP.V24I1.1308

Pavel Sladek, Milos Maryska, Lea Nedomova, Petr Doucek

Received: 2019-09-16 Accepted: 2019-11-01 Published: 2020-03-31

ABSTRACT

Purpose: This article proposes and analyses the potential use of IoT solutions for detecting water consumption not only from technical, but also from the business and financial points of view. This topic is important because by solving this problem, companies may save a lot of money and this paper provides financial analysis, which answers question, if the implementation is or is not meaningful.

Methodology/Approach: Source data used in this paper come from an extensive survey among fifty experts from the energy supply industry in the Czech Republic during two-round workshops. One of the most attractive application has been appointed “monitoring of utility consumption” – for this article the water metering.

Findings: We have reached the conclusion that an isolated implementation of IoT technologies is much more expensive than the current solution that are based on human labour, periodical inspections of meters by people. This is caused mainly by high prices of the sonic/mechanical metering devices supporting IoT functionality.

Research Limitation/implication: Workshops and research work were realised in conditions in the Czech Republic. Principles of application opportunities and of its implementation are general, but the final decisions about their importance can be influenced by the specifics and situation in the Czech Republic.

Originality/Value of paper: The value of the paper comes from the workshops where were defined important application opportunities for definition of the priority for each of defined application opportunities.

Category: Research paper

Keywords: Internet of Things; energy industry; utility measurement; Smart City; economic evaluation

1 INTRODUCTION

The potential of applications that are generally referred to as Internet of Things (IoT) has developed gradually – from its use in detecting the level of beverage cooling (Torre, Rad and Choo, 2019), to its application in systems with Radio-Frequency Identification (RFID) technologies all the way to nowadays it's very important role in the world of information and communication technologies (ICT).

By the year 2013, IoT had developed into a system that combines a very big quantity of different technologies with various functions. These technologies use different communication protocols on the basis of wireless data transmission, which is an important, but also very limiting, factor. For instance, sensors, GPS and mobile equipment, devices monitoring the movement of equipment, their remote switching off or on, etc. (Al-Roubaiey et al., 2019).

IoT can be perceived as an evolution of Internet which is characterized by the integration of not only mobile devices but also other things like sensors connected to cars, home appliances, different objects into one interconnected mesh (Perera et al., 2015).

As in the other areas, we recognize various definition of IoT. The first definition of IoT is defining IoT as a dynamic global network infrastructure, with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "Things" have identities, physical attributes and virtual personalities and use intelligent interfaces and are seamlessly integrated into the information system, has been generally accepted during the past two years (Van Kranenburg, 2008). The second definition, created by IEEE, defines (Minerva, Chebudie and Rotondi, 2015) Internet of Things as a: *"network of objects with embedded sensors connected to the Internet. Connectivity is one of the basic pillars of IoT"*.

We can recognize huge amount of areas, where can be IoT used to improve quality of life and quality of provided services. One of the key areas with high added value of implementation IoT for end user (or companies) is metering of utility consumption.

Metering utility consumption with the use of IoT is an important opportunity in the "Smart Environment" area.

One of the areas of implementation of IoT technologies, which is part of the "Smart environment" concept, is their use in the production and distribution of gas, potable water and electric power – utilities in general. We have conducted a survey concerning the applicability of individual solutions in this area from a technological and economic perspective (Maryska et al., 2018). This article focuses on one application opportunity – inspection – specifically on the detection of utility consumption, which can also help to detect fraud and long-term trends for the purposes of planning sufficient production capacities.

Electronic water meters with the function of remote reading help to reduce both non-technical water losses and the cost of physical reading of water consumption. Non-technical losses, also referred to as commercial losses, include e.g. un-metered fixed consumption, metering mistakes, billing or recording mistakes, incorrect meter installation, consumption below the sensitivity limit of water meters, water meter blocking, etc.

This concept is important for end users also. Current users prefer real-time access to information about their consumption of utilities, about situation in home (usually accessible via concept Smart home) etc. These concepts are closely related to visualization and real-time data analysis, which are another scientific topic solved in the area of IoT.

Except application areas we must mention, that application of IoT is closely connected with other negative factors, for example IoT security challenges (Jain and Singh, 2019; Nouichi et al., 2019; Moin et al., 2019), data security (Sittón-Candanedo, 2019), real-time data analytics (Fernández et al., 2019), energy consumption of IoT devices (Gunturi and Reddy, 2018; Liu et al., 2019), service innovation (Lee, Kao and Yang, 2014).

Mentioned solutions are part of one specific term, which is “Smart City”. The Smart City has a lot of definition. According to the European Commision, a Smart City is a place, where the standard networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business. The primary goal of a Smart City is to find a concept that makes it possible for facilities to ensure sustainable growth, an excellent quality of life, safety and efficient use of energies (Lombardi et al., 2012).

2 PROBLEM FORMULATION

The use of IoT in this industry (Basl and Doucek, 2019) and the “Smart City” concept is very topical. One of the important applications include the monitoring of utility consumption for the purposes of automatic invoicing and fraud detection. The goal of this article is to propose and analyse the potential use of IoT solutions for detecting actual water consumption.

A similar principle can be then applied to other areas as well, e.g. the reading of energy consumption, the identification of broken seals, etc. For this reason, this is a very topical matter because by solving this problem, companies may save a lot of money.

3 METHODOLOGY

The basic data identified for this article mostly come from an extensive survey among experts from the energy supply industry in the Czech Republic. The survey among 50 experts from different business companies and universities was conducted at the turn of 2016 and 2017.

To obtain relevant data, over 67 two-round workshops were conducted. The first round included 50 structured workshops, using questionnaires. Our questionnaires for asking questions and identifying technologies for IoT and business opportunities were based on the technique of guided questioning, with the use of open and closed questions (Rezanková, 2010).

Once all 50 workshops were finished, we processed and evaluated the data from the questionnaires that helped us to combine any identified duplicate application opportunities and to create a set of unique application opportunities.

In the second round of 17 workshops, experts and academicians evaluated 124 identified unique application opportunities and assigned to them priority from 1 to 3, where 1 was the most important and 3 the least important in terms of implementation.

It is important to add that the list of identified opportunities may always change, depending on workshop participants and actual changes of information technologies in IoT.

We extrapolated the results collected from the workshops to other utility supplies where we assume a situation similar to that in the energy supply industry (Abbate et al., 2019).

4 RESULTS

A complete detailed overview of the results is provided and commented on in the article (Maryska et al., 2019). Using the three-level priority scale, we identified 16 application opportunities with priority 1, 20 application opportunities with priority 2 and 25 application opportunities with priority 3. We identified additional 63 application opportunities but we did not assign any priority to them due to differently evaluated factors, such as importance, costs, implementation speed, societal benefits, etc.

In this article we focus on one of the application opportunities with priority 1, specifically on "automatic reading of water consumption" that provides for many other uses, on the condition that it is done on a regular basis.

The entire systematic solution for detecting the integrity of seals can be divided into five steps as already mentioned in the article (Doucek, Maryska and Nedomova, 2019) focused on the integrity of seals. The five identified steps are as follows:

- Technical solution;
- Sensors;
- Communication in the IoT network;
- Work with data prior to transmission;
- Power supply.

4.1 Technical Solution – Description

An electronic water meter is a device that contains an electronic chip that collects data about the volume of consumed water and transmits such data to the end recipient. In this case, the standard mechanical water consumption reading is not used and water consumption/through-flow is metered based on ultrasound transmission between two elements inside the electronic water meter. Identified data are electronically transmitted to the remote end recipient, or more precisely, to a cloud database where they are processed for the end recipient by the data service provider.

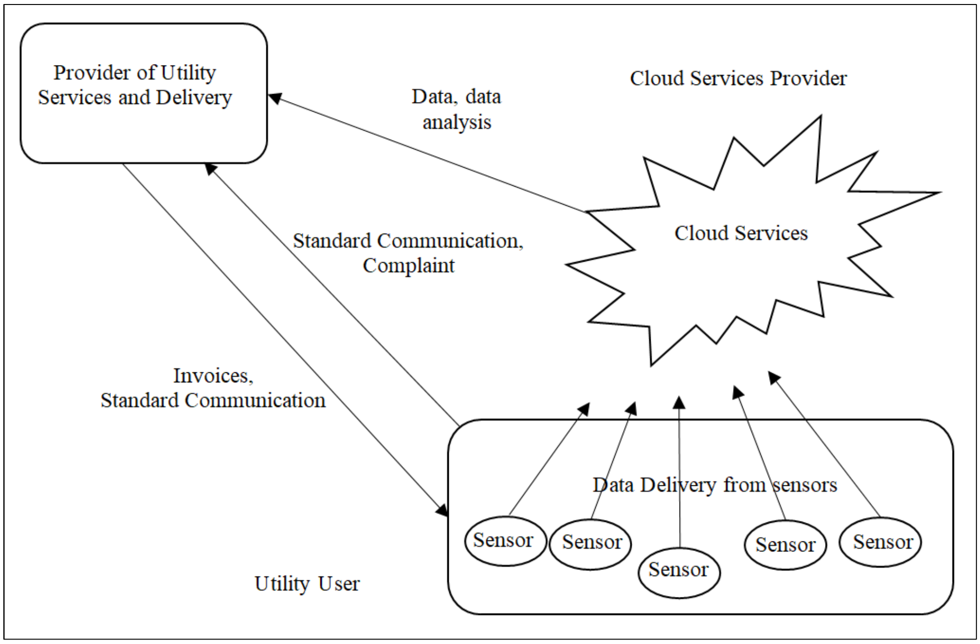


Figure 1 – Communication Concept for IoT Technology

4.2 Sensors

A sensor means a general device that can be used to identify the actual consumption of utilities and to transmit information about a seal or electronic water meter that was tampered with.

It is always a single-purpose device and cannot service more than one water meter, contrary to sensors detecting broken seals.

We propose to use as a transmission IoT network NB-IoT because it is protected against interaction of devices or SIGFOX because, based on conducted tests, it is much more resistant against interference than other low-energy IoT networks. NB-IoT and SIGFOX are the only networks with sufficient all-state coverage (Kim and Kim, 2019). Interference is a key factor because one apartment can have, and usually has, several water meters. One electronic hot and cold-water meter must be placed on every ascending pipe.

What is also important about these solutions is that the device sends a message with information about battery voltage both during transmission and in idle state together with the chip temperature on a regular basis, usually every 24 hours. Another important part is the unique identification of the sensor (its ID). However, the most important information is the actual water consumption identified at the time of transmission. Every sent message is signed and encoded into a hash message by the algorithm AES128. This guarantees the integrity of the transmitted message.

In the context of the aforesaid single-purposiveness, we should say that thanks to the different method of working with identified data and thanks to installed seals for tampering validation, electronic water meters also provide other functions such as:

- Identification of cracks in the water supply network behind the user's water meter;
- Water meter tampering or blocking;
- Water supply failure/interruption e.g. due to water meter de-installation or attempted fraud;
- Reverse water flow – in this case, reverse water flow does not reduce the volume of consumed water as in the case of standard mechanical water meters.

4.3 Communication in the IoT Network

The device in IoT networks usually does not register in the network when sending data. The device sends the message immediately upon the data transmission request. No confirmation of message receipt is usually required in the IoT network. The robustness and guaranteed likelihood of message delivery is achieved thanks to four mechanisms that are described in detail in the article

(Doucek, Maryska and Nedomova, 2019). The key factors are: triple transmission, a high penetration of base stations for signal reception, the use of message identifiers with incremental ID.

4.4 Work with Data Prior to Transmission

It is often discussed whether or not it is necessary to process the data prior to transmission. In the case of this type of message and communication, it is not necessary to pre-process the data in any major way. A defined information message is transmitted from the sensor only if the status changes or a specific event occurs, such as e.g. time or tampering with the water meter, etc.

4.5 Power Supply

Power supply is another important parameter of IoT solutions (Gomez et al., 2019). A battery is usually used for this type of sensor. Considering how the battery is used, its expected useful life is up to 16 years (Gomez et al., 2019). For the cost-effectiveness purposes, let’s assume that its useful life is 15 years. The device is designed as low-energy because it is independent of any external source of energy to ensure that the device could not be tampered with during a power outage (Abbas and Yoon, 2015).

5 RESULTS AND DISCUSSION

All prices are based on market and internet research among companies developing IoT solutions and companies, which are using these IoT solutions (utilities providers).

Based on our survey among sensor manufacturers, the price of an IoT device with the function of electronic data transmission and sonic metering of water consumption and with an expected 15-year useful life is about 5,000 CZK. An alternative is a standard mechanical water meter with the function of electronic data transmission; the investment cost of the water meter with a 5-year useful life is about 600 CZK and the investment cost of the set for remote reading with an unlimited useful life is about 2,500 CZK. In both cases, it is necessary to add installation and operating costs of the device in the IoT network. Installation costs are about 200 CZK per device (regardless of the type of device), operating costs are about 100 CZK per year (regardless of the type of device), the cost of device validation every five years is about 200 CZK (only for the sonic metering option).

Assuming a 15-year useful life, total annual costs are as follows:

- In the case of sonic metering:

  5,000 CZK + 3x200 + 2x200 + 15x100 = 7,500 CZK/15 years

  = **500 CZK average annual operating and investment costs.**

- In the case of mechanical metering:

  3x600 CZK + 2,500 CZK + 3x200 + 15x100 = 6,200 CZK/15 years

  = **410 CZK average annual operating and investment costs.**

When speaking of costs, we must always take into consideration benefits, proceeds or his reduction of other related costs.

When there are no technologies or no technologies are used that automatically inform the utility provider about the condition of the device, the device must be checked by a person to ensure its integrity and to identify utility consumption (water, electric power, gas).

Contrary to electrometers that are usually in hallways and thus generally accessible, water meters are always inside buildings/apartments. Therefore, it takes much longer to read/check water meters than electrometers. However, more devices can be check in one apartment since they are placed on every ascending pipe for hot and cold water.

For our analysis, it is necessary to take into account the price of a mechanical water meter with a 5-year useful life, which is on average 500 CZK, and the cost of its replacement. The installation of a new water meter costs 200 CZK. Considering the 15-year cycle, the average annual price of a standard water meter is *3x500 + 3x200 = 2,100/15 years = 140 CZK + the cost of reading*.

Let’s assume that an average three-room apartment has three hot water meters (in the kitchen, bathroom and WC) and one cold water meter.

Let’s assume that one person can check on average 30 apartments during one work shift, i.e. about 120 water meters (four apartments and 16 water meters per hour during an 8-hour work shift). It is an average value; more meters can be checked in a housing development in a big city than in a less densely populated location where it takes several or even dozens of minutes to get from one meter to another. The same applies to the number of water meters in a family home that usually has only two water meters, one cold water meter and one hot water meter.

Therefore, one person can check about 600 apartments per month, i.e. about 7,000 apartments per year. If we assume about 500,000 apartments, i.e. 2,000,000 water meters, we will need at least 70 employees who will check and monitor the situation. Considering the average wage in Prague, which is about 40,000 CZK, it amounts to 34 million CZK in annual costs (when considering the company’s costs and disregarding bonuses). To this amount, we must add the employee’s cost of transportation between metering stations and the ineffective loss of his time, etc. The annual costs will be about 70 million CZK. The average annual cost of checking one apartment is about 140 CZK for one reading, i.e. 35 CZK per water meter.

If we add the identified amount of 35 CZK to the cost of standard water meters, we will get the average annual cost of about 175 CZK per water meter as compared to 410 CZK or 500 CZK for both options of remote electronic water meter reading.

If we assume a one-off replacement of all water meters with new sonic electronic water meters, the cost will be extreme. Investment and operating costs for 15 years will amount to approximately 15 billion CZK, which we calculated as follows: the number of apartments x the average number of water meters per apartment x average annual investment and operating costs for 15 years, i.e. about 1 billion CZK per year.

If we assume a one-off replacement of all water meters with new mechanical water meters with remote reading, investment and operating costs for 15 years will amount to approximately 12.3 billion CZK, i.e. approximately 820 million CZK per year.

If we assume a one-off replacement of all water meters with new mechanical water meters, investment and operating costs for 15 years will amount to approximately 4.2 billion CZK, i.e. approximately 280 million CZK per year. When we add another 85 million CZK for manual reading, annual costs will amount to approximately 370 million CZK, i.e. not quite 37% of the cost of electronic reading in the case of sonic meters and 45% in the case of mechanical water meters with remote reading.

This shows that a switch to either option of remote water meter reading is not currently profitable. Nevertheless, we must also take into account potential savings resulting from a timely detection of fraud, the cost of collecting the due amount or potential court fees and legal fees, etc. as well as a higher service value for customers because we can inform them about a water leak. However, it is difficult to calculate this without knowing well the data.

If we assume that the checking and reading takes place twice a year, the cost of reading goes up and the disadvantage of remote reading diminishes.

6 CONCLUSIONS

Based on the forecast of the Gartner Company (Panetta, 2017), we can expect a mass expansion of applications of different comprehensive “Smart City” projects that will be based on IoT technologies. These technologies can be applied in different areas of human activities, e.g. an IoT device monitoring the movement of vehicles to prevent unnecessary trips (Campero-Jurado et al., 2019), a device monitoring parking lot occupancy, a device monitoring excessive noise and many others (Jia et al., 2019).

In this article, we focused on one specific application opportunity, which is the use of IoT sensors monitoring utility consumption (water, gas, electric power as well as the volume of transmitted data). In our case, it is the application for monitoring water consumption with the use of water meters based on IoT technologies. End customers have water meters allowing on-line reading of water

ISSN 1335-1745 (print) ISSN 1338-984X (online)

consumption. It also makes it possible to detect any potential attempt to illegally tamper with water consumption, such as water meter blocking, reverse water flow, etc.

The main benefits of these solutions are as follows:

- Immediate identification of tampering with a water meter;
- Online information about actual consumption;
- Easy installation;
- Additional services, such as information about the risk of a water leak, etc.

Negative factors include the limited useful life of the device, which is usually 15 years. This disadvantage is however compensated by the fact that e.g. mechanical water meters are replaced once every five years. Gas meters and electrometers are replaced about this often as well.

The current cost of implementation of the innovative solutions is another negative factor. The calculations in this article clearly show that the solutions are modern but the cost of their implementation currently hinders their mass expansion.

The volume of radio communications mainly in densely populated locations represents another risk factor because it could interfere with the signal transmitted from water meters and even with the entire network. Potential interference could be also caused by bad weather – heavy rain, fog (Venticinque and Amato, 2019) or snow.

Identified results are highly dependent on current market prices, nevertheless importance of this analysis is emphasise by the fact, that Metering the Consumption of Utilities was identified by Czech citizens as top priority of IoT implementation.

Our results are confirms, that before any decision the proper economic analysis (for example cost benefit analysis) has to be done. This analysis should show that not all IoT technology models are cost effective.

ACKNOWLEDGEMENTS

Paper was processed with contribution of long-term support of scientific work on Faculty of Informatics and Statistics, University of Economics, Prague (IP 400040).

REFERENCES

Abbas, Z. and Wonyong, Y., 2015. A Survey on Energy Conserving Mechanisms for the Internet of Things: Wireless Networking Aspects. *Sensors*, [e-journal] 15(10), pp.24818-24847. DOI: 10.3390/s151024818.

Abbate, T., Cesaroni, F., Cinici, M.C. and Villari, M., 2019. Business models for developing smart cities. A fuzzy set qualitative comparative analysis of an IoT platform. *Technological Forecasting and Social Change,* [e-journal] 142(C), pp.183-193. DOI: 10.1016/j.techfore.2018.07.031.

Al-Roubaiey, A., Sheltami, T., Mahmoud, A. and Yasar, A., 2019. EATDDS: Energy-aware middleware for wireless sensor and actuator networks. *Future Generation Computer Systems-the International Journal of Escience,* [e-journal] 96, pp.196-206. DOI: 10.1016/j.future.2019.01.060.

Basl, J. and Doucek, P., 2019. A Metamodel for Evaluating Enterprise Readiness in the Context of Industry 4.0. *Information*, [e-journal] 10(89), pp.1-13. DOI: 10.3390/info10030089.

Campero-Jurado, I., Quintanar-Gomez, J., Vargas-Buitron, O.D., Trejo-Macotela, F.R., Robles-Camarillo, D. and Simancas-Acevedo, E., 2019. Embedded system based on IoT and V2X for Smart Cities. *International Journal of Combinatorial Optimization Problems and Informatic,* 10(3), pp.50-58.

Doucek, P., Maryska, M. and Nedomova, L., 2019. The Application of IoT in the Area of Detection. In: University of Hradec Králové, *Hradec Economic Days, International Scientific Conference.* Hradec Králové, Czech Republic, 05-06 February 2019. Hradec Králové: University of Hradec Králové. pp.128-134.

Fernández, A.M., Gutiérrez-Avilés, D., Troncoso, A. and Martínez-Álvarez, F., 2019. Real-Time Big Data Analytics in Smart Cities from LoRa-Based IoT Networks. In: F.M. Álvarez, A.T. Lora, J.A.S. Munoz, H. Quintián and E. Corchado, *14th International Conference on Soft Computing Models in Industrial and Environmental Applications (SOCO 2019)*. Seville, Spain, 13-15 May 2019. Springer, Cham. pp.91-100.

Gomez, C., Veras, J.C., Vidal, R., Casals, L. and Paradells, J., 2019. A Sigfox Energy Consumption Model. *Sensors*, [e-journal] 19(3), 20p. DOI: 10.3390/s19030681.

Gunturi, Sri Krishna Sankalp and M. Sai Krishna Reddy. 2018. IoT Based Domestic Energy Monitoring Device. In: IEEE (Institute of Electrical and Electronics Engineers), *3rd International Conference for Convergence in Technology, I2CT 2018.* Pune, India, 6-8 April 2018. IEEE.

Jain, A. and Singh, T., 2019. Security Challenges and Solutions of IoT Ecosystem. *Advances in Intelligent Systems and Computing,* [e-journal] 933, pp.259-270. DOI: 10.1007/978-981-13-7166-0_25.

Jia, M., Komeily, A., Wang, Y. and Srinivasan, R.S., 2019. Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Automation in Construction*, [e-journal] 101, pp.111-126. DOI: 10.1016/j.autcon.2019.01.023.

Kim, D. and Kim, S., 2019. Gateway Channel Hopping to Improve Transmission Efficiency in Long-range IoT Networks. *KSII Transactions on Internet and Information Systems*, [e-journal] 13(3), pp.1599-1610. DOI: 10.3837/tiis.2019.03.027.

Lee, J., Kao, H. and Yang, S., 2014. Service innovation and smart analytics for Industry 4.0 and big data environment. *Procedia CIRP,* [e-journal] 16, pp.3-8. DOI: 10.1016/j.procir.2014.02.001.

Liu, X., Qin, Z., Gao, Y. and McCann, J.A., 2019. Resource allocation in wireless powered IoT networks. *IEEE Internet of Things Journal,* [e-journal] 6(3), pp.4935-4945. DOI: 10.1109/JIOT.2019.2895417.

Lombardi, P.L., Giordano, S., Farouh, H. and Yousef, W., 2012. Modelling the smart city performance. *Innovation: The European Journal of Social Sciences Research,* [e-journal] 25(2), pp.137-149. DOI: 10.1080/13511610.2012.660325.

Maryska, M., Doucek, P., Nedomova, L. and Sladek, P., 2018. The Energy Industry in the Czech Republic: On the Way to the Internet of Things. *Economies,* [e-journal] 6(2), 13p. DOI: 10.3390/economies6020036.

Maryska, M., Doucek, P., Sladek, P. and Nedomova, L., 2019. Economic Efficiency of the Internet of Things Solution in the Energy Industry: A Very High Voltage Frosting Case Study. *Energies,* [e-journal] 12(4), 16p. DOI: 10.3390/en12040585.

Minerva, R., Chebudie B.A. and Rotondi, D., 2015. Towards a definition of the Internet of Things (IoT). *IEEE Internet Initiative,* [online] Available at: <https://www.researchgate.net/publication/317588072_Towards_a_definition_of_the_Internet_of_Things_IoT> [Accessed 29 April 2019].

Moin, S., Karim, A., Safdar, Z., Safdar, K., Ahmed, E. and Imran, M., 2019. Securing IoTs in distributed blockchain: Analysis, requirements and open issues. *Future Generation Computer Systems,* [e-journal] 100, pp.325-343. DOI: 10.1016/j.future.2019.05.023.

Nouichi, D., Abdelsalam, M., Nasir, Q. and Abbas, S., 2019. IoT Devices Security Using RF Fingerprinting. In: Aconf, *Advances in Science and Engineering Technology International Conferences, ASET 2019.* Dubai, United Arab Emirates, 26 March-10 April 2019. IEEE.

Panetta, K., 2017. CIOs focused on smart cities should plan infrastructure to support the IoT. *Gartner*, [online]. 27 March 2017. Available at: <https://www.gartner.com/smarterwithgartner/smart-cities-look-to-the-future> [Accessed 29 April 2019].

Perera, C., Liu, C.H., Jayawardena, S. and Chen, M., 2015. A Survey on Internet of Things from Industrial Market Perspective. *IEEE Access,* [e-journal] 2, pp.1660-1679. DOI: 10.1109/ACCESS.2015.2389854.

Rezanková, H., 2010. *Analýza dat z dotazníkových šetření.* 2nd ed. Praha: Professional Publishing.

Sittón-Candanedo I., 2019. A New Approach: Edge Computing and Blockchain for Industry 4.0. In: E. Herrera-Viedma, Z. Vale, P. Nielsen, A.M. Del Rey and R.C. Vara, eds, *16th International Conference, Special Sessions. DCAI 2019. Advances in Intelligent Systems and Computing*. Springer, Cham. DOI: 10.1007/978-3-030-23946-6_25.

Torre, G., Rad, P. and Choo, K.R., 2019. Implementation of deep packet inspection in smart grids and industrial Internet of Things: Challenges and opportunities. *Journal of Network and Computer Applications,* [e-journal] 135, pp.32-46. DOI: 10.1016/j.jnca.2019.02.022.

Van Kranenburg, R., 2008. *The Internet of Things: A Critique of Ambient Technology and the All-Seeing Network of RFID.* Amsterdam, the Netherlands: Institute of Network Cultures.

Venticinque, S. and Amato, A., 2019. A methodology for deployment of IoT application in fog. *Journal of Ambient Intelligence and Humanized Computing*, [e-journal] 10(5), pp.1955-1976. DOI: 10.1007/s12652-018-0785-4.

ABOUT AUTHORS

Pavel Sladek – (P.S.) University of Economics in Prague, Czech Republic, Faculty of Informatics and Statistics, Department of Information Technologies, Ph.D. student, e-mail: pavel.sladek@vse.cz, Author's ORCID: 0000-0003-0266-1737.

Milos Maryska – (M.M.) University of Economics in Prague, Czech Republic, Faculty of Informatics and Statistics, Department of Information Technologies, Assoc. Professor, e-mail: milos.maryska@vse.cz, Author's ORCID: 0000-0003-2783-4657.

Lea Nedomova – (L.N.) University of Economics in Prague, Czech Republic, Faculty of Informatics and Statistics, Department of System Analysis, Asst. Prof., e-mail: nedomova@vse.cz, Author's ORCID: 0000-0002-8499-959X.

Petr Doucek – (P.D.) University of Economics in Prague, Faculty of Informatics and Statistics, Head of the Department of System Analysis, Prof., e-mail: doucek@vse.cz, Author's ORCID: 0000-0002-5647-661X.

AUTHOR CONTRIBUTIONS

P.S. – formal analysis, investigation, data resources; M.M. – conceptualization, methodology, writing original draft; P.D. – writing original draft, paper finalization; L.N. – formal analysis, investigation, final paper preparation, formatting.

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.

Setting Organisational Culture to Develop Potential and Innovativeness

DOI: 10.12776/QIP.V24I1.1346

Lucie Vnoučková, Hana Urbancová

Received: 2019-11-18 Accepted: 2020-03-11 Published: 2020-03-31

ABSTRACT

Purpose: The article aims to identify approaches influencing impact of organisational culture on development of innovation potential in organisations.

Methodology/Approach: The data were obtained by questionnaire survey in organisations operating in the Czech Republic (n = 207) that represented all sectors of Czech economy.

Findings: In today's highly competitive environment, organisations need to focus on setting an organisational culture that will support the development of all employees' knowledge and potential. The results have shown that the surveyed organisations are characterised by two basic approaches to setting the organisational culture for creating innovations: either an emphasis on relationships and collaboration or an emphasis on productivity.

Research Limitation/implication: The limit of the article may be seen in a relatively small sample of respondents; however, with respect to the stratified sampling the sample is representative.

Originality/Value of paper: The contribution of this paper lies in the identification and evaluation of approaches to support innovation potential based on type of organisational culture. The practical contribution lies in identification of approaches used to set efficient organisational culture and in presenting concrete results from real organisations that redesigned their culture and identified efficient variables for its design and implementation. The results are important for development of efficient approaches to organisational culture.

Category: Research paper

Keywords: quality; efficiency; innovation; organisation; productivity; approach

1 INTRODUCTION

In today's competitive environment innovations developed in organisations help to develop competitiveness. Innovations support improvement of processes and increase product efficiency. Innovations drives competitive advantage thanks to development of new products, services, efficient process set-up, etc. that enable organisations to meet customer needs in the shortest time and as best as possible (Adams, et al., 2019; Corstjens, Carpenter and Hasan, 2019; Grinza and Quatraro, 2019; Bocken et al., 2014).

The growing importance of information, knowledge and innovation in today's competitive environment has brought fast process of interrelated changes impacting each employee of an organisation, individual teams and the entire organisation (Cerne, Jaklic and Skerlavaj, 2013; Avolio, Walumbwa and Weber, 2009). To develop innovation potential, every organisation needs knowledge, new skills, flexible working conditions and setting of organisational climate and culture that support development of innovations and each individual's innovation potential. Every employee is a bearer of knowledge and has potential that an organisation can use to its advantage. So far, research results show that innovation activities of organisations are limited by lack of qualified human resources in organisations (Hitka et al., 2017; Diesel and Scheepers, 2019; Acebo and Viltard, 2018; Kampf, Hitka and Ližbetinová, 2019; Kiron et al., 2013).

Skilled human resources, individual employees of organisations, are absolutely necessary and irreplaceable when creating innovations, quality research and development, and implementing innovation processes. However, employees' knowledge, skills and abilities must be developed continuously (Urbancová, 2013; Stachová and Kachaňáková, 2011). Therefore, it must be stated that in order to remain competitiveness, it is essential that employees need to be able to continue their learning, improve their qualifications and capitalise their potential (Nidumolu, Prahalad and Rangaswami, 2009; Cerne, Jaklic and Skerlavaj, 2013; Avolio, Walumbwa and Weber, 2009). The right set up of organisational culture plays important role in organization and has important implications for managerial action in area of employee development and using of their potential. However, research on the links between culture and innovation remains limited.

The article aims to identify approaches influencing impact of organisational culture on development of innovation potential in organisations.

The article consists of four main parts. The first part summarise theoretical assumptions and leads to synthesis of the latest research findings in the given field. Chapter Methodology describes research methods and procedures. Results present research outcomes and implications. Discussion presents comparison of achieved results with similar researches in the studied field. Particular recommendations for organisations are presented in Conclusions section.

1.1 Theoretical Background

The shorter expiry-time of information, constant need to expand knowledge and skills and rapid development of ICT have completely rebuilt labour market by reducing number of low-skilled jobs and increasing number of jobs with high demands of skills, competences and education together with necessity of flexibility. This has resulted not only in the change in the work life in organisations but also in a greater emphasis on continuous development of every individual and focus on innovations (Geradts and Bocken, 2019; Jin, Navare and Lynch, 2019; Huo, Motohashi and Gong, 2019). The cultural context in which an organisation operates influences the level of innovation (Lijauco et al., 2020). Organisations need to adapt to modern trends in management, continual changes in markets and external environment, and these changes must be reflected in an organisational environment setting (Chen et al., 2018; Stankiewicz and Lychmus, 2017). Also, organizational sustainability significantly intervenes in the interaction of organizational culture and innovation (Srisathan, Ketkaew and Naruetharadhol, 2020). It is necessary to realise that innovation is in its core applied new knowledge, which is a valuable organisational resource linked to human element, since the bearer of knowledge is always and employee.

In the globalised economic environment, not only organisations but also entire states compete, and their competitiveness no longer depends solely on material resources, but primarily on employee knowledge, knowledge creation, its preservation and sharing, and, last but not least, its use. Continuous development, increasing individual knowledge, skills, qualifications and experience will improve the innovation potential of individuals, teams and organisations in all types of innovation that are distinguished in practice which is confirmed by atuhors (Leopold, 2019; Hollensbe et al., 2014; Cerne, Jaklic and Skerlavaj, 2013; Bocken et al., 2014; Stachová, Stacho and Vicen, 2017).

First and foremost, employees can help their organisation to effectively set processes (process innovations) by implementation of their ideas, for example by introducing new or improved production or delivery methods. Employee commitment to organisational culture impacts knowledge creation, and openness to change, and positively influence employees' knowledge creation (Chai, Song and You, 2020). Significant effect of organizational culture on organizational sustainability in cultural characteristics and to maintain the core business competencies as marketing, operations, customer orientation, and financial management (Srisathan, Ketkaew and Naruetharadhol, 2020). This innovation type can lead to reduction in material consumption and labour costs for the organisation and to improvement in working conditions for employees, etc. The result is a profit growth, possibility to launch new variants of the marketing strategy compare to competition, etc. In addition, employees can use their ideas to assist in marketing innovations by introducing new marketing methods that an organisation has not used yet (e.g. redesigning product and its packaging, placing it on the market through new sales channels, new pricing strategy, etc.). To use current innovations and to support employees' potential for new innovations, the type of organisational innovation is very important. In this area, a new organisational method is introduced in business practices of the organisation, in structure of jobs or in external relations (e.g. by creating a new type of cooperation with suppliers). Last but not least, it is necessary to mention product innovations that improve organisation's market position (Grinza and Quatraro, 2019; Adams et al., 2016; Bocken et al., 2014). The fact that an organisation comes up with a new product or service brings about several advantages, primarily in building a brand, not only of the product/service, but also the employer's brand.

Without employees and their knowledge, however, organisations will find it very difficult to achieve innovations, as innovators are mostly talents that need to be constantly developed and supported in their creativity and their activities by suitable set working and organisational conditions (Urbancová, 2013). It is necessary to realise that organisation's performance is not exceeding based on its resources it has, but it depends mainly on quality of its employees. People working in organisation and having the same values as management are the most valuable capital. When managing innovations themselves, it is necessary to maintain a rational attitude of organisation's management towards innovations, i.e. to continually model situations of threats, to consider risks, and last but not least, to think about new products and innovation of every area In organisation. Again, it is up to employees - high-quality managers to reveal weak, sometimes hidden signals that customers send to express their needs, and to be able to search for them. In other words, nowadays it is impossible to innovate within organisations without high-quality employees (Lenihan, McGuirk and Murphy, 2019; Wei, Kang and Wan, 2019; Geradts and Bocken, 2019; Acebo and Viltard, 2018).

Culture is usually manifested through the beliefs and values related to various organizational aspects which influence the overall performance, outputs and innovations in an organisation (Lijauco et al., 2020). To ensure that employees can be continuously developed, it is necessary to set the appropriate organisational culture which supports employee development and considers reasonable expenses on development. The expenses dedicated to employee development can be considerd as an investment that will return to organisation (Liao, 2018; Messick et al., 2019). If organisational climate and organisational culture are set improperly inefficient use of working time, problems and conflicts in the workplace, employee turnover and ineffective communication can occur instead of innovations and progressive use of employees' innovation potential and labour productivity (Leopold, 2019; Kiron et al. al., 2013; Nidumolu, Prahalad and Rangaswami, 2019). From the organisation's perspective, current organisational culture should be in harmony with strategically designed organisational culture. The nature of current organisational culture can be overcome by changes in organisation's economic, social or technical environment and by change in its market position by a takeover or merge (Messick et al., 2019; Wei, Kang and Wan, 2019; Acebo and Viltard, 2018).

The relationship between organisational culture and innovation has recently been increasingly monitored and researched by many authors worldwide. Many researchers focus on research in various environments and sectors, regions and states, especially in developed countries, but there are also studies mapping the influence of organisational culture on innovation in developing countries, as reported by Sánchez-Báez, Fernández-Serrano and Romero (2019), Büschgens, Bausch and Balkin (2013), and Lemon and Sahota (2004). However, research in this area in the Czech Republic has not been conducted yet. Since organisational culture is specific to every organisation and represents a fundamental principle of functioning of an organisation, it is necessary to pay attention to it. The effectiveness with which culture is used in an organisation is reflected in organisation's ability to achieve results and innovations (Martins and Terblanche, 2003). The external organisational culture, i.e. the one perceived by competitors, potential customers and employees plays an important role in every organisation. Every organisation is perceived by its stakeholders through selected elements of culture and one of them is employee development and innovation potential. These elements of culture influence the brand of an organisation either in a positive or negative sense. This impacts an organisation's position in the market and also possible recruitment and retention of high-quality and talented employees with potential. To develop their innovation potential, organisations need knowledge, abilities and skills of their employees. Therefore, innovations can only be achieved when employees' potential is continuously developed and increased. Based on above mentioned, this article deals with setting a suitable organisational culture that supports employee development and their innovation potential.

2 METHODOLOGY

The data were obtained by quantitative research focused on innovations and innovation potential by means of a questionnaire survey in n = 207 organisations. In total, 860 e-mails to owners or management of organisations were sent out, 207 returned. The e-mail return rate was 24.06%. The sample was selected from the Albertina database of organisations. The quota sample size was defined using the Krejcie and Morgan (1970) formula (N = 2,700,000) from Albertina database, with required confidence level at 95% (standard value of 1.96), the acceptable deviation rate = 0.03 and the expected deviation rate r = 0.04). Using this statistical approach to the sample size based on the above-mentioned rates was met by the conducted survey (n = 207). The minimum number of respondents was set at 164.

The questionnaire was filled by middle or higher management of addressed organisations, in case of smaller organisation the owner himself filled the questionnaire (the responses therefore reflected the point view of organisational heads/owners/managers). The questionnaire respected the ethical aspect and anonymity of respondents. The survey contained 16 questions: 4 identification questions (sector, area of business activities, size, part of a larger organisation) and 12 research questions which are further processed evaluated in this article. All questions were closed-ended (allowing only one response, multiple choice) and with more response options.

Pilot survey was used to test the questionnaire. Small sample of organisational representatives were asked to fill the questionnaire and the questions and possible answers were discussed with them. Based on this feedback, the final questionnaire was adjusted and finalized.

The questionnaire focused on the following areas: importance of innovations in organisation, importance of development and maintain innovative culture, support of innovative culture in organisation, sources used to stimulate innovation, problem solving at individual level in organisation, common way of project and task solving, top areas of innovation in organisation, identification of groups of employees involved in innovation process, procedure of employee involvement in innovation processes, characterization of a typical manager focusing on innovations, importance of ergonomics in organisation, system of ergonomics in organisation and ways of its ensuring.

The structure of respondents (n = 207) was as follows:

- *Sector:* 81.6% – private; 18.4% – public;
- *Internationalisation:* 45.4% – international organisation; 12.6% – local organisation; 27.5% – national organisation; 14.5% – regional organisation;
- *Part of group of organisations*: 44.9% is part of a larger group; 55.1% is single owned;
- *Size of the organisation*: 21.3% with 1 – 9 employees; 26.1% with 10 – 49 employees; 23.2% with 50 – 249 employees; 29.5% with 250 and more employees.

The following null hypotheses were tested:

$H_0$1: There is no significant dependence between focus of organisational culture and sector where an organisation operates.

$H_0$2: There is no significant dependence between focus of organisational culture and market (national vs. international).

$H_0$3: There is no significant dependence between focus of organisational culture and ownership of an organisation.

$H_0$4: There is no significant dependence between focus of organisational culture and size of the organisation (number of employees).

The results were analysed using statistical tools – the dependence test ($\chi 2$) and the power of dependence test (Cramer's V). In cases where the determined p-value was below the significance level of $\alpha = 0.05$, the null hypothesis was rejected because data demonstrated statistical dependence between qualitative variables. In such cases, the strength of dependence was determined using Cramer's V coefficient. The strength of correlation was interpreted in accordance with the categories of De Vaus (2014). For the purposes of the dependence test, the responses in the questionnaire were merged into dichtomic structure (answer was marked or was not marked).

To identify further relationships between variables, factor analysis (multivariate statistics) was used based on adequate quality of dependencies found in the data matrix. The factor analysis was conducted after the correlation analysis and the principal component analysis. We used the Varimax method and the Kaiser-Guttman rule for selection of significant variables to form factors according to Anderson (2009). The factor was considered for further evaluation only if the value was greater than 1 (initial loading); values of variables exceeding 0.3 were considered significant to form the factor.

The statistical software used to evaluate the data was IBM SPSS Statistics 24.

3 RESULTS

Based on the results, it can be summarised that the surveyed organisations have their organisational cultures set to support knowledge and experience sharing among employees in order to strengthen innovation potential of individuals, teams and the entire organisation. Representatives of organisations were asked which operating areas were innovated. Representatives could select more answers. The results shown that organisations surveyed mostly innovated working procedures (24.9%), quality of work (19.3%), labour productivity (16.7), and the portfolio of products and services (12.7%).

To specify setting of organisational culture in line with the focus on the type of innovations, dependencies between organisational characteristics were determined, see Table 1.

The Table 1 shows dependencies between setting of organisational culture and the fact whether the organisation is part of a multinational company and size of the organisation (the strength of dependence ranges from 0.192 to 0.323, which is a weak to medium dependence).

The results show that setting of organisational culture affects the decline in labour productivity (5.6%), efficient use of working time (14.8%), problematic interpersonal relationships in the workplace (16.7%), high staff turnover (11.1%), insufficient communication between individual organisational units (22.2%), discrepancy between the current culture of organisation and strategically needed organisational culture (7.4%), overcoming the nature of current organisational culture by changes in economy, social or technical environment of organisation (16.7%) and change in the market position of organisation by an acquisition and/or merge (5.5%).

Table 1 – Dependencies between Focus of Organisational Culture and Selected Qualitative Characteristics (Source: Authors' Own Calculation based on Survey)

Focus of organisational culture	**Absolute frequencies**	**%**	**Dependence of the organisation on:**			
			Sector	*Market*	*Ownership*	*Size*
			Relationship (p-value/Cramer's V)			
Orientation on results	51	24.6	NO (0.880)	YES (0.022/0.211)	YES (0.003/0.201)	YES (0.000/0.323)
Orientation on customer	44	21.3	NO (0.177)	NO (0.103)	YES (0.005/0.192)	YES (0.021/0.211)
Orientation on quality	48	23.2	NO (0.441)	NO (0.282)	NO (0.142)	YES (0.006/0.237)
Orientation on innovation	28	13.5	NO (0.652)	NO (0.164)	YES (0.001/0.233)	YES (0.004/0.246)
No focus on innovation	36	17.4	x	x	x	x

To examine the mutual relationships between variables in more detail, the data were processed using multivariate statistics according to Anderson (2009); the factor analysis identified 2 factors influencing aspects of organisational culture (see Table 2).

Table 2 – Variance Explained by Factors (Source: Authors' Own Calculation based on Survey)

Factor	**Total Variance**	**Total % of Variance**	**Cumulative % of Variance**
1	3.977	49.717	49.717
2	1.131	14.134	63.851

The factor analysis identified 2 significant factors combining analysed variables. The first factor explains approximately 50% of the sample, the second factor 14%. Table 3 shows the results of the factor analysis in detail. The areas described in methods section on organisational culture were examined.

According to the results shown in Table 3, respondents in the sample can be divided into two groups. The first group of variables comprises variables of organisational climate setting, primarily based on interpersonal relationships (0.743), appropriate communication (0.858) and changes in the social, economic and technical environment of organisation that affect staff turnover (0.779). These areas, including communication, relationships and staff turnover, contribute to the primary reason to reset organisational culture of almost half of surveyed organisations. The identified factor can be named "Organisational

Culture Supporting Collaboration" and it explains 49.717% of sample. It is obvious that variables related to employees and their satisfaction within organisation are essential. The lack of emphasis on communication and relationships often results in staff turnover. If an organisation realizes this mistake, a new setting of organisational culture is effective tool to eliminate negative areas. This leads to ideal use of human resources that subsequently creates innovations. A functioning organisational culture involving collaboration, high-quality relationships and communication leads to knowledge and information sharing, creativity and value creation for an organisation.

Table 3 – Resultant Factors Determined by the Varimax Method (Source: Authors' Own Calculation based on Survey)

Variable	**Factor 1**	**Factor 2**
Decline in labour productivity	0.062	**0.903**
Efficient use of working time	0.464	**0.711**
Problematic interpersonal relationships in the workplace	**0.743**	0.174
High staff turnover	**0.779**	0.175
Insufficient communication between individual organisational units	**0.858**	0.316
Discrepancy between the current culture of organisation and strategically needed organisational culture	0.235	**0.769**
Overcoming the nature of current organisational culture by changes in economy, social or technical environment of organisation	**0.473**	0.430
Change in the market position of organisation, acquisition and/or merge	**0.662**	0.134
Total % of Variance	*49.717*	*14.134*
Name of the factor	*Culture supporting collaboration*	*Culture supporting productivity*

In contrast, the second identified factor involves re-setting of the organisational culture based on decrease in the labour productivity (0.903), efficient use of working time (0.711) and setting of a strategically effective organisational culture (0.769). The factor focuses on development of employee potential through a suitable working environment that supports knowledge and experience sharing and innovation potential. The identified factor that characterises approximately 15% of sample can be named "Organisational Culture Supporting Productivity". It can be stated that in this case organisational culture is set up to increase labour productivity, not the area of internal collaboration, as was the case of the first factor.

Both factors characterise the strategic approach of using organisational culture to enhance organisation’s ability to work more efficient and to generate innovations. Either in terms of interconnection and collaboration of employees, or in terms of efficient use of time and thus increasing the labour productivity. The results develop practice in defining key criteria of innovative approach to build organisational culture and its efficient use to support innovations. The results may inspire other researchers to conduct further research in other conditions and deepen the knowledge of the relationship between organisational culture and innovation potential.

4 DISCUSSION

Nowadays, innovation is an indisputable part of modern society and a prerequisite for long-term competitiveness, both for individual organisations or states, as confirmed by conclusions of Kiron et al. (2013) or Grinza and Quatraro (2019). Innovation is an intentionally proposed change, with which, however, only employees of organisations can come up with, as stated by authors Urbancová (2013), Hitka et al. (2019). The change organisations focus on depends on abilities of employees and it relates to products and services, manufacturing processes or management methods used in an organisation for the first time. In the official statistical survey of the Czech Statistical Office, innovations in organisations are monitored at the technical (product and process) and non-technical (marketing and organisational) levels.

As stated by the Czech Statistical Office (2019), the innovation activity of organisations in the Czech Republic in 2016 increased for the first time since the economic crisis, mainly due to the growing efforts of small organisations. Also, for the first time, more financial resources were invested in the research and development than in the so-called non-knowledge innovations. But it is still not enough to match the European Union average.

Czech Statistical Office (2019) also published innovation activities of Czech organisations from 2014 to 2016. The data clearly show that in the mentioned period 46.3% of Czech organisations innovated their products, processes, marketing or organisational methods. Compared to the period of 2012-2014, this is an increase in innovation activity of organisations by 4%. Thus, the negative trend of a decline in innovation activities brought about by the economic crisis in 2008 has stopped. However, it is necessary to realise that organisational culture and organisation’s external presentation are a tool to support innovations. Based on research results, suitable organisational culture:

- creates organisation’s “image”, provides and facilitates a clear view of an organisation,

- increases organisation's attractiveness,
- creates and strengthens customer orientation, high quality of products and services,
- increases customer loyalty and satisfaction with organisation's products and services, and
- clarifies relationship between organisation and external stakeholders.

These results were also obtained by analysis made in this article. Organisations work with their culture for greater loyalty, strengthening relationships, better quality of work and improvement of organisation's climate.

In today's highly competitive environment, continuous and sustained innovation means not only innovation of products and processes, but also the development of human talents and management, as confirmed by the results that have shown the importance of setting the organisational culture in order to support knowledge and experience sharing among employees with a view to strengthening innovation potential of individuals, teams and the entire organisation, as was also evidenced by the research by Geradts and Bocken (2019), Chen et al. (2018), and Leopold (2019).

5 CONCLUSION

The organisational culture has significant impact on employee development as well as on their innovation potential. The research results show that organisation's focus on a particular type of innovation is influenced by the organisation's size and ownership. Innovations are supported in all sectors of Czech economy. Results identified two factors that characterise level of innovation potential based on employee development. Firstly, it is suitable setting of organisational culture to support collaboration (49.7% of the sample) and setting of organisational culture to support productivity (14.1% of sample). The first factor involves importance of high-quality relationships and communication among employees to increase the organisation's success and innovation potential. The second factor points to the approach of productivity increase through appropriate setting of organisational culture. Such elements operate as a significant mediator contributing to performance to manage innovation.

The results can improve practical approaches in defining the key criteria of building organisational culture and its efficient use to support innovations. The contribution of this paper lies in identification of approaches to organisational culture that may support innovation potential. The practical contribution lies in presenting concrete results from real organisations that redesigned their culture and identified efficient variables which affect the resultant approach to increase innovation potential. Application of approaches found by factors improves development of innovation and organisational culture.

As a practical contribution, this paper suggests managers to realise the crucial elements of organisational culture, such as relationships, communication, and organizational climate, to improve performance by combining organisational efficiency in their strategic decisions made during the innovation processes.

The limits of the article may be seen in a relatively small sample of respondents; however, with respect to the stratified sample representing the real structure of organisations in the Czech Republic the sample can be stated as sufficient. The results may inspire other researchers to conduct further research in other conditions and deepen knowledge about relationship between organisational culture and innovation potential.

REFERENCES

Acebo, M.N. and Viltard, L.A., 2018. Corporate Culture: A Key to Stimulate Innovation. *Independent Journal of Management & Production*, [e-journal] 9(3), pp.869-888. DOI: 10.14807/ijmp.v9i3.735.

Adams, R., Jeanrenaud, S., Bessant, J., Denyer, D. and Overy, P., 2016. Sustainability-oriented Innovation: A Systematic Review. *International Journal of Management*, 18(2), pp.180-205.

Anderson, V., 2009. *Research Method in Human Resource Management*. 2nd ed. London: Chartered Institute of Personnel Development.

Avolio, B.J., Walumbwa, F.O. and Weber, T.J., 2009. Leadership: Current Theories, Research, and Future Directions. *Annual Review of Psychology*, 60, pp.421-449.

Bocken, N.M.P., Short, S.W., Rana, P. and Evans, S., 2014. A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, [e-journal] 65, pp.42-56. DOI: 10.1016/j.jclepro.2013.11.039.

Büschgens, T., Bausch, A. and Balkin, D.B., 2013. Organizational culture and innovation: A meta-analytic review. *Journal of Product Innovation Management*, 30(4), pp.763-781.

Cerne, M., Jaklic, M. and Skerlavaj, M., 2013. Authentic leadership, creativity, and innovation: A multilevel perspective. *Leadership*, [e-journal] 9(1), pp.63-85. DOI: 10.1177/1742715012455130.

Chai, D.S., Song, J.H. and You, Y.M., 2020. Psychological Ownership and Openness to Change: The Mediating Effects of Work Engagement, and Knowledge Creation. *Performance improvement quarterly* (Accepted for publication 05 February 2020). DOI: 10.1002/piq.21326.

Chen, Z., Huang, S., Liu, Ch., Min, M. and Zhou, L., 2018. Fit between Organizational Culture and Innovation Strategy: Implications for Innovation Performance. *Sustainability*, [e-journal] 10(10), 18p. DOI: 10.3390/su10103378.

Corstjens, M., Carpenter, G. S. and Hasan, T. M., 2019. The Promise of Targeted Innovation. *Mit Sloan Management Review*, 60(2), pp. 39-44.

Czech Statistical Office (CSO), 2019. Inovace v českých firmách jsou na vzestupu. *Vědavýzkum.cz*, [online] 06 November 2018. Available at: <https://vedavyzkum.cz/politika-vyzkumu-a-vyvoje/politika-vyzkumu-a-vyvoje/inovace-v-ceskych-firmach-jsou-na-vzestupu> [Accessed 20 September 2019].

De Vaus, D.A., 2014. *Surveys in Social Research.* 6th edition. Routledge.

Diesel, R. and Scheepers, C.B., 2019. Innovation climate mediating complexity leadership and ambidexterity. *Personnel Review*, [e-journal] 48(7), pp.1782-1808. DOI: /10.1108/PR-11-2018.

Geradts, T.H.J. and Bocken, N.M.P., 2019. Driving Sustainability-Oriented Innovation Organizations Can Innovate to Address Environmental and Social Problems but They Need to Build the Right Culture. *Mit Sloan Management Review*, 60(2), pp.78-83.

Grinza, E. and Quatraro, F., 2019. Workers' replacements and firms' innovation dynamics: New evidence from Italian matched longitudinal data. *Research Policy*, [e-journal] 48(9), pp.1-1. DOI: 10.1016/j.respol.2019.05.013.

Hitka, M., Lorincova, S., Lizbetinova, L., Bartakova, G.P. and Merkova, M., 2017. Cluster Analysis Used as the Strategic Advantage of Human Resource Management in Small and Medium-sized Enterprises in the Wood-Processing Industry. *BioResources*, [e-journal] 12(4), pp.7884-7897. DOI: 10.15376/biores.12.4.7884-7897.

Hollensbe, E., Wookey, Ch., Hickey, L., George, G. and Nichols, C.V., 2014. Organizations with Purpose. *Academy of Management Journal*, [e-journal] 57(5), pp.1227-1234. DOI: 10.5465/amj.2014.4005.

Huo, D., Motohashi, K. and Gong, H., 2019. Team diversity as dissimilarity and variety in organizational innovation. *Research Policy*, 48(6), pp.1564-1572.

Jin, Z., Navare, J. and Lynch, R., 2019. The relationship between innovation culture and innovation outcomes: exploring the effects of sustainability orientation and firm size. *R & D MANAGEMENT*, [e-journal] 49(4), pp.607-623. DOI: 10.1111/radm.12351.

Kampf, R., Hitka, M. and Ližbetinová, L., 2019. Direction of the Corporate Culture in Slovak and German Transport Companies from a Top Managers' Perspective. *Periodica Polytechnica Transportation Engineering*, [e-journal] 47(3), pp.213-219. DOI: 10.3311/PPtr.11166.

Kiron, D., Kruschwitz, N., Reeves, M. and Goh, E., 2013. The Benefits of Sustainability-Driven Innovation. *Mit Sloan Management Review*, 54(2), pp. 69-73.

Krejcie, R.V. and Morgan, D.W., 1970. Determining sample size for research activities. *Educ. Psychol. Meas*., 30, pp.607-610.

Lemon, M. and Sahota, S.P. 2004. Organizational Culture as a Knowledge Repository for Increased Innovative Capacity. *Technovation*, 24(6), pp.483-498. DOI: 10.1016/S0166-4972(02)00102-5.

Lenihan, H., McGuirk, H. and Murphy, K.R., 2019. Driving innovation. *Public policy and human capital Research Policy*, [e-journal] 48(9), 103791. DOI: 10.1016/j.respol.2019.04.015.

Leopold, H., 2019. Innovation through Culture and Communication. *Elektrotechnik Und Informationstechnik,* 136(3), pp.225-225.

Liao, Z., 2018. Corporate culture, environmental innovation and financial performance. *Business Strategy and The Environment*, 27(8), pp.1368-1375.

Lijauco, F., Gajendran, T., Brewer, G. and Rasoolimanesh, S.M., 2020. Impacts of Culture on Innovation Propensity in Small to Medium Enterprises in Construction. *Journal of construction engineering and management*, [e-journal] 146(3), 04019116. DOI: 10.1061/(ASCE)CO.1943-7862.0001753.

Martins, E.C. and Terblanche, F., 2004. Building Organizational Culture That Stimulates Creativity and Innovation. *European Journal of Innovation Management*, 6(1), pp.64-74. DOI: 10.1108/14601060310456337.

Messick, A., Borum, C., Stephens, N., Brown, A., Kersey, S. and Townsend, B., 2019. *Creating a Culture of Continuous Innovation. Nurse Leader*, [e-journal] 17(4), pp.352-355. DOI: 10.1016/j.mnl.2018.10.005.

Nidumolu, R., Prahalad, C.K. and Rangaswami, M.R., 2009. Why Sustainability Is Now the Key Driver of Innovation. *Harvard Business Review*, 87(9), 16p.

Sánchez-Báez, E.A., Fernández-Serrano, J. and Romero, I., 2019. Organizational culture and innovation in small businesses in Paraguay. *Regional Science Policy and Practice*. (Accepted for publication 15 February 2019).

Srisathan, W.A., Ketkaew, C. and Naruetharadhol, P., 2020. The intervention of organizational sustainability in the effect of organizational culture on open innovation performance: A case of thai and chinese SMEs. *Cogent business & management*, [e-journal] 7(1), 1717408. DOI: 10.1080/23311975.2020.1717408.

Stachová, K. and Kachaňáková, A., 2011. Organisational Culture Analysis in Companies Operating in Slovakia. *Scientia Agriculturae Bohemica*, 42(2), pp. 87-92.

Stachová, K., Stacho, Z. and Vicen, V., 2017. Efficient involvement of human resources in innovations through effective communication. *Business: Theory and Practice*, [e-journal] 18, pp.33-42. DOI: 10.3846/btp.2017.004.

Stankiewicz J. and Lychmus P., 2017. Corporate core values and professional values of Generation Y from the perspective of the effectiveness of ethics programs. *Management-Poland*, [e-journal] 21(1), pp.95-110. DOI: 10.1515/manment-2015-0082.

Urbancová, H., 2013. Competitive Advantage Achievement through Innovation and Knowledge. *Journal of Competitiveness*, [e-journal] 5(1), pp.82-96. DOI: 10.7441/joc.2013.01.06.

Wei, Y.L., Kang, D. and Wan, Y.Z., 2019. Geography, culture, and corporate innovation. *Pacific-Basin Finance Journal*, [e-journal] 56, pp.310-329. DOI: 10.1016/j.pacfin.2019.06.010.

ABOUT AUTHORS

Lucie Vnoučková – (L.V.) University of Economics and Management, Czech Republic, Department of Management, Assoc. Prof., e-mail: lucie.vnouckova@vsem.cz, Author's ORCID: 0000-0003-4296-875X.

Hana Urbancová – (H.U.) University of Economics and Management, Czech Republic, Department of Human Resources, Asst. Prof., e-mail: hana.urbancova@vsem.cz, Author's ORCID: 0000-0001-6603-8691.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this article. L.V. and H.U. – conceptualization, resources, validation, writing review and editing.

CONFLICTS OF INTEREST

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

The Effectiveness of Innovative Infrastructure: The Case of Kazakhstan

DOI: 10.12776/QIP.V24I1.1406

Bakyt Bayadilova, Arsen Nassyrkhanov, Elvira Tlessova,
Lyazzat Parimbekova, Maigul Tolymgozhinova, Tursynzada Kuangaliyeva

Received: 2020-02-25 Accepted: 2020-03-13 Published: 2020-03-31

ABSTRACT

Purpose: The development of an innovative economy is constrained by the problems of science funding, modernization of scientific institutions and innovative training of specialists. This article focuses on the problem of evaluating the effectiveness of the innovation infrastructure of the Republic of Kazakhstan using a systematized set of performance indicators.

Methodology/Approach: Approaches to assessing innovation infrastructure have been analysed. Based on the analysis, correlation and regression assessment model has been developed.

Findings: A forecast has been made for innovative infrastructure development based on the obtained performance indicators. This forecast is of high practical significance, as it allows predicting the outcomes of innovation.

Research Limitation/implication: In the light of globalization, it is extremely urgent to develop an innovative economy along with regional innovation systems. If combined, these systems can accelerate the innovation processes in the regions, ensure competitiveness and expedite the socio-economic development. The formation of an innovative economy should be in line with the productive forces and production relations.

Originality/Value of the paper: Through categorization, this study establishes a set of underlying indicators, which are used to measure the performance of the innovation infrastructure. A model of correlation and regression analysis is built, which allows evaluating the effectiveness of the innovation infrastructure of Kazakhstan.

Category: Research paper

Keywords: efficiency; forecast; infrastructure; innovation; national economy

1 INTRODUCTION

Currently, the effective use of innovative potential, which is the basis of an innovative economy, is becoming one of the prerequisites for achieving sustainability and quality of economic growth throughout the world. The main problem is to determine the factors, criteria and indicators of innovation infrastructure, build a mathematical model for evaluating effectiveness based on correlation and regression analysis and develop forecasts for innovation infrastructure development. The main difficulties in fulfilling the innovative potential are related to the lack of organizations' own funds, limited budget and extra-budgetary financing, including borrowed funds. At the same time, foreign direct investment in most cases brings innovations in the form of technology transfer, new approaches to management, etc. In this regard, when developing an innovative strategy, it is necessary to synchronize it with the investment policy. All this leads to the creation of an investment and innovation climate in the country where certain changes are necessary in the taxation system, distribution of investment preferences, protection of property rights and interests of all participants in the business process.

Scientific and technical developments do not always become innovative products, which are ready for production and effective implementation. The activation of innovative activity requires, on the one hand, coordination of actions of all public administration bodies and, on the other hand, the integration of all interested parties in the implementation of innovations, attracting investments, creating conditions conducive to the innovation process and introducing the achievements of science and technology to the country's economy.

The study aims to systematize performance indicators for the innovation infrastructure of Kazakhstan and to build a model for the assessment of its effectiveness.

In modern economic analysis, econometrics is one of the major directions that uses empirical methods to evaluate economic relationships (Aliyev and Shahverdiyeva, 2018). The Innovation Scoreboard divides European countries in four groups according to their innovation performance and captures 80 indicators, distinguishing between four categories of economic knowledge (Dogru, 2020).

Another assessment methodology focuses on comparable factors, which influence innovativeness. This methodology is based on the index method that includes the following indices: access to financing; innovation activity; best practices; internationalization; activity in the field of intellectual property (Simeonova-Ganeva et al., 2013). These indices allow the implementation of descriptive statistics, frequency allocations and rank criteria for the examination of correlations between factors. They also allow the creation of new models for multiple linear regressions to access the impact of factors involved in the innovation process (Kalaydzhieva, 2016).

Existing approaches use indicators characterizing the innovative potential of the country, the functional index allows evaluating the functional efficiency, while the resource and structural indices describe the state of the innovative infrastructure. However, no comparison was provided for the infrastructure efficiency and safety. Besides, methods using expert estimates deliver less accurate and reliable results (Kharitonova and Krivosheeva, 2012; Fomina et al., 2019).

In modern economic literature, the study and evaluation of the innovative potential of industrial enterprises receive increasing attention. Previous studies described a diverse methodology for assessing the innovative development of a region and a strategic management system (Kortelainen and Lättilä, 2013; Tafti, Jahani and Emami, 2012). A set of indicators, developed by Kazantsev (2012), do not fully improve the accuracy of quantitative measurements. Rauter et al. (2019) studied openness of firms' economic innovation measures (Stefan and Bengtsson, 2017) in the context sustainable development. Organizational culture affects openness in innovation (Brettel and Cleven, 2011; Wiener, Gattringer and Strehl, 2018), it also influences sustainability of innovative companies (Globocnik, Romana and Baumgartner, 2020). The company's strategy in terms of the influence of internal and external factors is fundamental to improving the effectiveness of innovation (Faems et al., 2010). Openness in innovation implies a loss of control, managerial and organizational complexity, and, consequently, increased costs (Manzini, Lazarotti and Pellegrini, 2017). Despite the existence of various forms of open innovation approaches (Hossain, 2010; Mustaquim and Nyström, 2014), there is a need to change the design of goods, services and processes in accordance with the sustainable development requirements of both customers and non-governmental organizations and the state (Ketata, Sofka and Grimpe, 2015; Tsai and Liao, 2017).

Framework Programs (FP) of European Commission finance research projects of consortia in the field of innovation, whose partners consist of representatives of firms (SMEs and large firms), universities, government research centers and government agencies from different countries (Barajas, Huergo and Moreno, 2012). Firstly, FP projects are funded through grants from the European Commission and own funds of the consortium partners. Direct financial assistance to R&D through grants stimulates socially significant projects. Secondly, FP encourage R&D collaboration between partners, through which revenue increases in such consortia (Nepelski, Van Roy and Pesole, 2019). FP influence the mission of creating new opportunities in the market and the further development of industries (Audretsch and Link, 2016; Leyden, 2016; Mazzucato, 2016). The problems of management of industrial enterprises in general and, in particular, the problems of management of their sustainable innovative development were investigated in the works (Amah, 2017; Sorokin and Novikov, 2019; Tuguskina, 2019; Usov et al., 2018; Ustinova and Sirazetdinov, 2017).

The article aims to investigate the following:

- assessment methods of innovative potential;
- the formation of a strategy for company's innovative development;
- most effective methods of innovative infrastructure development.

2 METHODS

For the innovation infrastructure of Kazakhstan, performance indicators were systematized by categorizing activities that take place within the innovation infrastructure: financial, information provision & consulting, production & research, employment & salary payment (Table 1).

Table 1 – Indicators for Assessing Innovation Infrastructure in Terms of Effectiveness (Source: Developed by the Authors)

Financial Activity (F)	**Information Provision & Consulting (I)**	**Production & research (P)**	**Employment &salary payment (E)**
F1. Internal R&D costs	I1. Number of advanced technologies created	P1. Number of research organizations	E1. Number of researchers
F2. R&D work scope	I2. Total protection documents issued	P2. Fixed assets for R&D	E2. Average salary for a researcher
F3. Innovation spending	I3. Exports of innovative products	P3. Volume of brand new products	E3. Number of advanced researchers
	I4. Total protection requests issued	P4. Internal equipment-related costs	

Data from 2012-2019 reports of the Agency of the Republic of Kazakhstan on Statistics (hereinafter, the Statistics Agency) were processed to fit groups described earlier. A correlation and regression analysis was performed and the correlation coefficients, paired and general, were calculated. All calculations were carried out using the Microsoft Excel software (Table 2).

Table 2 – The Set of Indicators to Find Dependence between the Volume of Innovative Products and Factors of Innovation Infrastructure (Source: Author's Own Elaboration Adapted from Reports of the Statistics Agency)

Indicator, million tenge	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Total volume of innovative products	65,020.40	74,718.50	120,408.40	156,039.90	152,500.60	111,531.60	82,597.40	142,166.80
F1. Internal R&D costs	11,643.50	14,579.80	21,527.40	24,799.90	26,835.50	34,761.60	38,988.40	33,466.82

Indicator, million tenge	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
F2. R&D work scope	14,374.60	18,549.50	29,591.30	35,571.60	37,041.80	40,172.50	36,998.40	44,577.90
F3. Innovation spending	26,933.10	35,360.30	67,088.90	79,985.90	83,523.40	11,3460.10	61,050.90	235,501.70
I1. Number of advanced technologies created	533.00	599.00	787.00	920.00	702.00	823.00	487.00	1,037.00
I2. Total protection documents issued	3,211.00	2,870.00	4,034.00	4,097.00	3,071.00	5,382.00	5,707.00	6,358.00
I3. Exports of innovative products	43,944.80	48,076.00	65,686.10	81,149.90	82,841.60	60,655.70	34,259.50	73,393.50
I4. Total protection requests issued	5,782.00	6,045.00	5,168.00	6,118.00	6,175.00	6,237.00	0,5725.00	5,946.00
P1. Number of research organizations	273.00	295.00	390.00	437.00	438.00	421.00	414.00	424.00
P2. Fixed assets for R&D	9,037.30	12,396.60	14,584.20	19,247.70	18,782.00	19,176.70	22,003.27	22,810.90
P3. Volume of brand new products	9,538.90	21,384.70	44,133.10	88,416.50	107,585.80	89,650.30	71,591.50	12,4587.50
P4. Internal equipment-related costs	827.40	1,475.50	3,188.90	3,416.00	1,978.10	3,254.40	1,131.00	1,197.40
E1. Number of researchers	9,899.00	10,382.00	11,910.00	12,404.00	11,524.00	10,780.00	10,095.00	10,870.00
E2. Average salary for a researcher	29,348.00	34,946.00	41,512.00	51,400.00	64,108.00	81,810.00	90,325.00	103,571.00
E3. Number of advanced researchers	3,761.00	3,753.00	4,124.00	4,304.00	4,224.00	4,052.00	4,072.00	4,388.00

The strongest correlations with the volume of innovative products and the minimal correlations among themselves were established. By assessment, the most significant factors are the internal R&D costs (F1), the number of new technologies and solutions created (I1), the export of innovative products (I3), the internal equipment-related costs (P4), and the number advanced researchers (E3).

These indicators were applied in the subsequent regression analysis (Table 3) and substituted as coefficients in the following equation:

$$Y = 0.196x1 - 24.903x2 + 1.368x3 + 2.35x4 + 68.434x5 - 241745 \quad (1)$$

Where: *Y* – the volume of innovative products, million tenge; *X1* – the internal R&D costs, million tenge; *X2* – the number of new technologies created; *X3* – the export of innovative products, million tenge; *X4* – the internal equipment-related costs, million tenge; *X5* – number advanced researchers.

Table 3 – Results of the Correlation-Regression and Variance Analysis of Performance Indicators (Source: Author's Own Elaboration)

Regression statistics		**Analysis of Variance**					
Multiple R	0. 999	**Source**	**DF**	**SS**	**MS**	**F**	**P**
R-squared	0. 998	*Regression*	5	8,992,310,933.531	1,798,462,186.706	180.980	0.006
Adjusted R-squared	0.992	*Residue*	2	19,874,681.749	9,937,340.874		
Standard error	3,152.355	*Total*	7	9012185615.280			
	Coefficients	**Standard error**	**t-statistic**	**P-value**	**95% lower**	**95% upper**	
Y-intersection	-241,745.823	50,970.147	-4.743	0.042	-461,052.664	-22,438.981	
Ô1	0.195	0.244	0.800	0.508	-0.855	1.246	
È1	-24.903	11.510	-2.164	0.163	-74.428	24.622	
È3	1.368	0.172	7.942	0.015	0.627	2.109	
Ï4	2.350	1.435	1.638	0.243	-3.823	8.523	
Ê3	68.434	16.110	4.248	0.051	-0.880	137.748	

3 RESULTS

The results of regression analysis are presented in Table 3. As it turned out, only three factors have the strongest influence on the effectiveness of innovation infrastructure: the number of advanced researchers; the internal equipment-related costs; and the volume of innovative products. The more advanced researchers involved per a unit of output, the higher the mean volume of innovative products. One advanced researcher equals 68.43 million tenge. When internal costs of the equipment grow extra 1 million tenge, the innovative products generate additional 2.35 million tenge. If exports rise 1 million tenge, then the industry will produce additional 1.4 million tenge.

The effectiveness assessment model allows to predict the potential state of the innovation infrastructure. This requires knowledge about the behavior of the given factors.

To predict the buoyancy of indicators necessary, the following equations were applied:

- for F1:

$$Y = 10926X0.593, \tag{2}$$

with a coefficient of determination R2 = 0.954 that indicates high accuracy;

- for I1, a logarithmic function:

$$Y = 132.4\ln(x) + 560.4Y, \tag{3}$$

- for I3:

$$Y = 771.1x3 - 12168x2 + 57003x - 9908, \tag{4}$$

- for P4:

$$Y = -175.7x2 + 1577x - 557.1, \tag{5}$$

- for E3:

$$Y = 67.71x + 3780. \tag{6}$$

Based on these calculations, the values of performance indicators were forecasted. Afterwards, the regression equation (1) was applied to forecast the volume of innovative products (Table 4). As a result average annual growth rate of the volume of innovative products was 13.6%. The average annual growth rates for other indicators were as follows. The internal R&D costs are projected to grow 5.1%. The number of new technologies and solutions will increase by 1.08%. The exports of innovative products are expected to rise 16.2%. The internal equipment-related costs will become higher by 30.5% and the number of advanced researchers will grow 6.4%.

Table 4 – The Effect of Performance Indicators on the Volume of Innovative Products (Source: Author's Own Elaboration)

Year	Volume of Innovative Products – Forecast	F1	I1	I3	P4	E3
2007	66,692.51	11,643.50	533.00	43,944.80	827.40	3,761.00
2008	72,248.54	14,579.80	599.00	48,076.00	1,475.50	3,753.00
2009	122,427.70	21,527.50	787.00	65,686.10	3,188.90	4,124.00
2010	153,759.98	24,799.80	920.00	81,149.90	3,416.00	4,304.00
2011	153,046.26	26,835.50	702.00	82,841.60	1,978.10	4,224.00
2012	112,456.93	34,761.60	823.00	60,655.70	3,254.40	4,052.00
2013	81,917.25	38,988.40	487.00	34,259.50	1,131.00	4,072.00
2014	142,460.35	33,466.60	1,037.00	73,393.50	1,197.40	4,388.00
2015	149,610.47	40,209.35	851.31	79,642.90	422.88	4,307.37
2016	198,253.04	42,801.72	865.26	114,422.00	22.00	4,334.38
2017	277,505.59	45,290.49	877.88	171,131.10	-49.88	4,358.82
2018	394,015.54	47,688.72	889.40	254,396.80	330.96	4,381.13
2019	554,423.84	50,006.86	900.00	368,845.70	1,288.24	4,401.65

The effectiveness assessment model introduced in the study allows to predict the volume of innovative products. Such application justifies the practical significance of this model.

4 DISCUSSION

Supporting small innovative organizations is one of many ways to boost innovation activity and innovative susceptibility of the regions. Unlike developed countries, small innovative businesses in Kazakhstan do not drive the innovative growth and do not receive significant inflows of investment. At the present stage of economic development, various countries tend to provide various kinds of support, from innovation, to legal, organizational and financial. Kazakhstan is no exception here. The Government of the Republic of Kazakhstan established an effective innovation policy, which embraces issues related to the creation and implementation of innovations, promotion of innovations in foreign markets, and international cooperation in the field of innovation. Diverse indicators for R&D, e.g., the R&D personnel ratio, have positive effects on product and process innovations, while process innovations affect R&D intensity (Song and Oh, 2015). Business investment (Sosnowski, 2014) is defined as the primary indicator for measuring innovation activity and recognition of innovation corporations. R&D expenditures result in new knowledge and ties between various organizations, research institutes or universities (Cavdar and Aydin, 2015). Innovations such as those incorporated to improve production mediate the impact of R&D on further advances (Raymond and Saint-Pierre, 2010). Overall, high investment in innovation enhances innovation effectiveness (De Fuentes et al., 2015).

Innovative development requires an application of systematic approach, as it is not considered in terms of unilateral cause-and-effect relationships leading from R&D to innovation (Doskaliyeva and Orynbassarova, 2016). It presents interaction and feedback within the set of economic, social, organizational, financial and other factors that determine both the development of science-intensive industries and the commercialization of innovative activities (Manaenko, 2013). To promote investment and technological innovation activities, it is advisable to apply mechanisms and regulatory instruments, including models based on public-private partnership in the field of investment (Sun, Mitra and Simone, 2013). In particular, many well-known researchers made significant contribution to the theoretical foundations of innovation and investment processes (Bleda and Del Rio, 2013; Blind, 2016; Bloch and Bugge, 2013; Geels, 2013).

Industrial production occupies a significant place in the structure of GRP of the region – 41%. Figure 1 shows the GRP of East Kazakhstan region in 2016-2018.

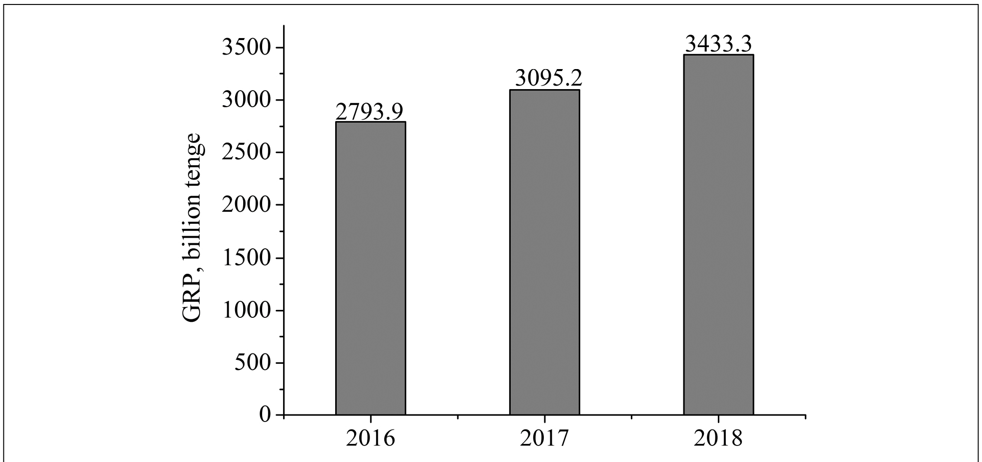


Figure 1 – The GRP of the East Kazakhstan Region in 2016-2018, billion tenge

In the region, there are car, bus and tractor assembly plants located, where, starting from the nodes and assemblies to the last screw, there is an urgent need to create production of the manufacturing of components for these assembly plants.

About 1.6 million hectares or 5.6% of the region territory is covered with high-trunk forests, which are represented by such species as fir, larch, spruce, cedar, aspen and birch, and where about 70% of the business wood of Kazakhstan is concentrated. At the same time, the woodworking industry, which was quite developed in the past, currently has a significant decline and needs to be restored. In order to develop small and medium-sized businesses using the resource potential of the forestry of the region, it is planned to implement two investment projects for processing low-speed, small-scale timber within the framework of the state program of industrial and innovative development. In 2018, the project "Reconstruction and development of woodworking and plywood-producing enterprises" was put into operation.

Agriculture is also a fairly developed sector of the economy today. In order to increase the productivity of animals, it is important to increase the efficiency of pastures in this direction. The volume of gross agricultural output compared to the corresponding period last year increased by 15.1% and amounted to 45.1 billion tenge. According to the index of physical volume of gross agricultural output, the region is on the 4th place in the Republic of Kazakhstan. The dynamics of agricultural development in terms of gross output in 2016-2018 is shown in Figure 2.

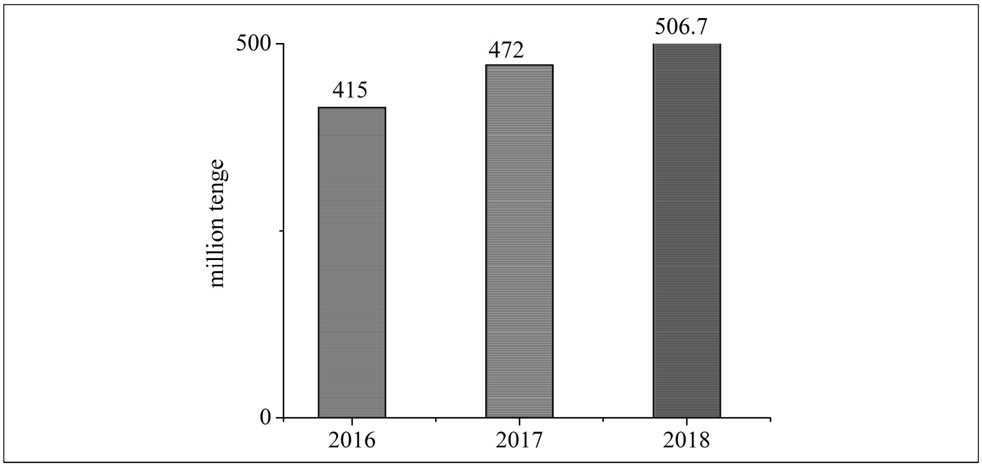


Figure 2 – The Gross Output of Agriculture 2016-2018 years, million tenge

However, due to the low water content, many pastures are not used effectively. In this regard, it is required to provide them with cattle drinking water through the drilling of deep water wells.

The agriculture of the region is mainly represented by animal husbandry, and there are rural regions that are exclusively engaged in animal husbandry. At the same time, enterprises for deep processing of livestock products are not developed in these regions.

The existing enterprises for processing of agricultural products also do not meet the existing requirements on the level of technological equipment and technology and require reconstruction and modernization.

The region has an inexhaustible potential of energy opportunities. In the annual (about 8 billion kWh) volume of electricity generation, about 70% is accounted for by hydroelectric power plants, and the rest by thermal power plants.

Small business is the most important component of the economy of the region and one of its main reserves (14% of the total number of Kazakhstan). The quantitative indicators are shown in Table 5.

Table 5 – Number of Existing Small and Medium-Sized Businesses in the Regions

Name of cities and areas	**Number of operating SMEs, units**		
	2016	2017	2018
Total	87,041	79,966	87,678
Ust-Kamenogorsk	27,204	26,424	28,466
Semey	21,343	18,047	20,880
Ridder	2,907	2,615	2,758
Kurchatov	555	468	486
Abay district	970	888	960
Ayagoz district	3,576	3,391	3,677
Beskaragai district	964	892	908
Borodulikha district	1,420	1,312	1,379
Glubokovsky district	2,398	2,273	2,354
Zharma district	1,822	1,566	1,715
Zaysan district	2,379	2,450	2,751
Katon-Karagaysky district	2,255	2,121	2,189
Kokpektinsky district	1,633	1,621	1,794
Kurchumsky district	1,684	1,633	1,715
Tarbagatai district	2,823	2,829	3,176
Ulan district	2,001	1,890	2,066
Urjar district	4,339	4,039	4,433
Shemonaiha district	2,586	2,341	2,508

The number of registered small and medium-sized enterprises (SMEs) is 111.0 thousand units or 99.9% by 2017. The number of active entities in the SME sector amounted to 87.7 thousand units or 109.6% by 2017. In 2018, the volume of output by SMEs amounted to 995.6 billion tenge, with an increase of 95.4 billion tenge or 110.6% to the corresponding period of 2017 (900.2 billion tenge). The index of physical volume (IFO) of output by SMEs – 104.6%.

Describing the effectiveness of the use of budget funds for research and development in Kazakhstan, it should be noted that at present, the total cost of research and development is practically not paid back by the cost of the amount of scientific and technical work performed. The Law of the Republic of Kazakhstan "On innovation" regulates relations in the field of innovation and defines the fundamental principles, directions and forms of implementation of state innovation policy. At the same time, special attention is paid to rapidly developing areas, in particular information and telecommunication technologies and electronics.

The system of indices, sub-indices and indicators used to measure technopole's performance has a hierarchical structure (Aliyev and Shahverdiyeva 2017; Shahverdiyeva, 2017). The first category of indicators consists, in fact, of only one index – the composite technopole index. The second category includes 10 indices, the third category – 106 sub-indices, and the fourth category – 320 macro/micro indicators, which embrace official statistics and other external and internal factors. The fourth-category of indicators plays a fundamental role in the expert measurement of the third- and second-category sub-indices, mostly. In this case, absolute indicators and their specific values are used. The approach varies depending on the context. A composite technopole index is made up of weight ratios given by the experts and specific indices that were examined in (Aliyev and Shahverdiyeva 2017; Bhattacharya and Saha, 2015). To measure technopole performance, the potential socio-economic indicators of technopole development are used alongside a correlation-regression analysis. As an investigated indicator, total innovative product or service production volume in the technopole has been accepted. Based on the initial values of performance indicators, the econometric model of technopole performance was established. To identify contributive factors, a pair correlation matrix has been implemented (Gusarova and Kuzmenkov, 2016; Shahverdiyeva 2017).

The ranking method used to evaluate complex performance is built around two categories of resources, production and innovation. For instance, decision on whether to initiate a technopole depends on the value of five indicators in the category of production resources (HER-X1, MTR-X2, SCP-X3, FFI-X4, SAF-X5). Indicators displaying the innovation background (INV-X6, SRE-X7, ECO-X8, SPD-X9, IRRX10) play an important role in the service-based technopole. The performance of some technopoles depends on the institutional environment (BTE-X11, INV-X12, HEA-X13). These factors, which were included in the regression models, were statistically significant and contributive to the total volume of products/services. Additional characteristics of the regression model allow to predict the performance of technopoles and calculate the volume of innovative products/services (Aliyev and Shahverdiyeva, 2018).

When comparing the present assessment model with the existing ones, the study established the common goal of the employment of mathematical methods in the innovative economy. Techniques used to ensure sustainable economic development and innovative production growth in technology parks are aimed at accelerating the formation of a knowledge-based economy.

The novelty of this study is that it identified factors, which, alongside the production-related costs, have the strongest impact on the performance of the innovation infrastructure. These factors are the exports of innovative products, the number of advanced researchers, and innovation spending.

5 CONCLUSIONS

Under conditions of globalization, regions will not be able to step on the path of socio-economic development without innovation strategies. Currently the development of innovative economy is constrained by problems in the field of science financing, laboratory modernization activities that are currently in action; specialist training issues; poor support of education; the lack of innovative susceptibility of business and low financial opportunities; and by an insufficient innovation infrastructure in the regions. In this regard, the formation of spatially localized innovative subsystems with strong bonds that are connecting science, education, and production is objectively necessary.

Through categorization, this study established a set of underlying indicators used to measure the performance of the innovation infrastructure. The set consists of indicators evaluating:

- financial activity: the internal R&D costs; the R&D work scope; and the innovation spending;
- information provision and consulting: the number of advanced technologies created; total protection documents issued; the exports of innovative products; total protection requests issued;
- production and research: the number of research organizations' fixed assets for R&D; the volume of brand new products; internal equipment-related costs;
- employment and salary payment: the number of researchers; average salary for a researchers; the number of advanced researchers.

A model of correlation and regression analysis was built, which allowed to evaluate the effectiveness of the innovation infrastructure of Kazakhstan. The analysis revealed that only three factors have the strongest influence on the effectiveness of innovation infrastructure: the number advanced researchers; the internal equipment-related costs; and the volume of innovative products.

An innovation infrastructure development forecast was made based on the behaviour of given performance indicators. The volume of innovative products was projected to increase 2.72-fold over the coming five years, reaching 39,318.59 million tenge in 2025.

REFERENCES

Agency of the Republic of Kazakhstan, 2019. *Growth rate of sectors of the national economy (Volume index, %).* [online] Ministry of National Economy of the Republic of Kazakhstan. Available through: Statistics committee <http://www.stat.gov.kz> [Accessed 03 November 2019].

Aliyev, A.G. and Shahverdiyeva, R.O., 2017. Scientific-methodological bases of development of the composite indicators system of comparative evaluation of technopoles' activity. *Problems of Information Society,* 1, pp.61-74.

Aliyev, A.G. and Shahverdiyeva, R.O., 2018. Application of mathematical methods and models in product-service manufacturing processes in scientific innovative technopoles. *International Journal of Mathematical Sciences and Computing,* [e-journal] 4(3), pp.1-12. DOI: 10.5815/ijmsc.2018.03.01.

Amah, E., 2017. Pro-activeness and survival of small and medium scale enterprises in Nigeria. *Journal of Small Business and Entrepreneurship Development,* [e-journal] 5(2), pp.67-72. DOI: 10.15640/jsbed.v5n2a7.

Audretsch, D.B. and Link, A.N., 2016. *Essays in public sector entrepreneurship*. Cham: Springer. DOI: 10.1007/978-3-319-26677-0.

Barajas, A., Huergo, E. and Moreno, L., 2012. Measuring the economic impact of research joint ventures supported by the EU framework programme. *The Journal of Technology Transfer,* [e-journal] 37(6), pp.917-942. DOI: 10.1007/s10961-011-9222-y.

Bhattacharya, B. and Saha, B., 2015. Analysis of signaling time of community model. *International Journal of Mathematical Sciences and Computing,* [e-journal] 2(2), pp.8-21. DOI: 10.5815/ijmsc.2015.02.02.

Bleda, M. and Del Rio, P., 2013. The market failure and the systemic failure rationales in technological innovation systems. *Research Policy,* [e-journal] 42(5), pp.1039-1052. DOI: 10.1016/j.respol.2013.02.008.

Blind, K., 2016. The impact of regulation on innovation. In: J. Edler, P. Cunningham and A. Gök, eds. 2016. *Handbook of innovation policy impact*. Cheltenham, UK: Edward Elgar Publishing. pp. 450-482.

Bloch, C. and Bugge, M., 2013. Public sector innovation – From theory to measurement. *Structural Change and Economic Dynamics,* [e-journal] 27(C), pp.133-145. DOI: 10.1016/j.strueco.2013.06.008.

Brettel, M. and Cleven, N.J., 2011. Innovation culture, collaboration with external partners and NPD performance. *Creativity and Innovation Management,* [e-journal] 20(4), pp.253-272. DOI: 10.1111/j.1467-8691.2011.00617.x.

Cavdar, S.C. and Aydin, A.D., 2015. An empirical analysis about technological development and innovation indicators. *Procedia – Social and Behavioral Sciences,* [e-journal] 195, pp.1486-1495. DOI: 10.1016/j.sbspro.2015.06.449.

De Fuentes, C., Dutrenit, G., Santiago, F. and Gras, N., 2015. Determinants of innovation and productivity in the service sector in Mexico. *Emerging Markets Finance and Trade,* [e-journal] 51(3), pp.578-592. DOI: 10.1080/1540496X.2015.1026693.

Dogru, C., 2020. Gaining Strategic Advantage through Social and Technological Innovation: Evidence from European Countries. In: E. Akdevel, D. Akella, D. Bingol, J. Crawford, C.M. Montaudon-Tomas, M. Pejic-Bach and R. Walden, 2020. *Leadership Styles, Innovation, and Social Entrepreneurship in the Era of Digitalization*. IGI Global. pp.25-43. DOI: 10.4018/978-1-7998-1108-4.ch002.

Doskaliyeva, B.B. and Orynbassarova, Y.D., 2016. Development of the system of investment support of projects in the industrial-innovative development of Kazakhstan. *International Journal of Environmental and Science Education*, 11(12), pp.5109-5127.

Faems, D., De Visser, M., Andries, P. and Van Looy, B., 2010. Technology alliance portfolios and financial performance: value-enhancing and cost-increasing effects of open innovation. *Journal of Product Innovation Management,* [e-journal] 27(6), pp.785-796. DOI: 10.1111/j.1540-5885.2010.00752.x.

Fomina, S., Sizikova, V., Shimanovskaya, Y., Kozlovskaya, S. and Karpunina, A., 2019. The effect of teaching and supply chain management on employees' skills in small and medium sized enterprises of Russia. *International Journal of Supply Chain Management*, 8(4), pp.930-938.

Geels, F.W., 2013. The impact of the financial–economic crisis on sustainability transitions: Financial investment, governance and public discourse. *Environmental Innovation and Societal Transitions,* [e-journal] 6, pp.67-95. DOI: 10.1016/j.eist.2012.11.004.

Globocnik, D., Romana, R. and Baumgartner, R.J., 2020. Synergy or conflict? The relationships among organisational culture, sustainability-related innovation performance, and economic innovation performance. *International Journal of Innovation Management,* [e-journal] 24(1), pp.2050004. DOI: 10.1142/S1363919620500048.

Gusarova, O.M. and Kuzmenkova, V.D., 2016. Modeling and analysis of the trends of development of regional economy. *Fundamental Research,* 3, pp.354-359.

Hossain, M., 2010. Open innovation: So far and a way forward. *World Journal of Science Technology and Sustainable Development,* [e-journal] 10(1), pp.30-41. DOI: 10.1108/20425941311313083.

Kalaydzhieva, V., 2016. The influence of innovation on increasing the competitiveness of industrial enterprises. *Journal of Varna University of Economics,* 60(3), pp.336-349.

Kazantsev, S.V., 2012. The assessment of resources and scale of innovative activity in the entities of the Russian Federation. *Innovations,* 8, pp.36-45.

Ketata, I., Sofka, W. and Grimpe, C., 2015. The role of internal capabilities and firms' environment for sustainable innovation: evidence for Germany. *R&d Management,* [e-journal] 45(1), pp.60-75. DOI: 10.1111/radm.12052.

Kharitonova, T.V. and Krivosheeva, T.M., 2012. Methodology for assessing the level of development and the effectiveness of the functioning of the innovation infrastructure of the region. *Bulletin of the Russian State University of Tourism and Service*, 2, pp.100-106.

Kortelainen, S. and Lättilä, L., 2013. Hybrid modeling approach to competitiveness through fast strategy. *International Journal of Innovation and Technology Management,* [e-journal] 10(5), pp.1-27. DOI: 10.1142/S0219877013400166.

Leyden, D., 2016. Public-sector entrepreneurship and the creation of a sustainable innovative economy. *Small Business Economics,* [e-journal] 46(4), pp.553-564. DOI: 10.1007/s11187-016-9706-0.

Manaenko, J.H., 2013. Investment maintenance of innovative development of electric power industry enterprises: Theoretical and methodological aspect. *Scientific-Methodical Journal of New Economy,* 2(62), pp.343-349.

Manzini, R., Lazzarotti, V. and Pellegrini, L., 2017. How to remain as closed as possible in the open innovation era: the case of Lindt & Sprüngli. *Long Range Planning,* [e-journal] 50(2), pp.260-281. DOI: 10.1016/j.lrp.2015.12.011.

Mazzucato, M., 2016. From market fixing to market-creating: A new framework for innovation policy. *Industry and Innovation,* [e-journal] 23(2), pp.140-156. DOI: 10.1080/13662716.2016.1146124.

Mustaquim, M.M. and Nyström, T., 2014. Designing information systems for sustainability–the role of universal design and open innovation. In: M.C. Tremblay, D. et al., eds., *International Conference on Design Science Research in Information Systems, Advancing the Impact of Design Science: Moving from Theory to Practice.* Miami, USA, 22-24 May 2014. Cham, Springer. pp.1-16. DOI: 10.1007/978-3-319-06701-8_1.

Nepelski, D., Van Roy, V. and Pesole, A., 2019. The organisational and geographic diversity and innovation potential of EU-funded research networks. *The Journal of Technology Transfer,* [e-journal] 44(2), pp.359-380. DOI: 10.1007/s10961-018-9692-2.

Rauter, R., Globocnik, D., Perl-Vorbach, E. and Baumgartner, R.J., 2019. Open innovation and its effects on economic and sustainability innovation performance. *Journal of Innovation & Knowledge,* [e-journal] 4(4), pp.226-233. DOI: 10.1016/j.jik.2018.03.004.

Raymond, L. and Saint-Pierre, J., 2010. R&D as a determinant of innovation in manufacturing SMEs: an attempt at empirical clarification. *Technovation,* [e-journal] 30(1), pp.48-56. DOI: 10.1016/j.technovation.2009.05.005.

Shahverdiyeva, R.O., 2017. Development of an econometric model of innovative products or services in technology parks. In: Institute Economy of Azerbaijan National Academy of Sciences (ANAS), *International scientific-practical conference on "Strategic economic reforms: Preventive Tax Policy".* Baku, Serbia, 12 October 2017. Baku: Institute Economy of ANAS. pp.587-594.

Simeonova-Ganeva, R., Vladimirov, Z., Ganev, K., Panayotova, N., Dimitrova, T., Davidkova, T. and Ivanova Yordanova, D., 2013. *A study of entrepreneurship and the prospects for innovations development in SMEs (2012-2013).* [online] Bulgarian version. Available at SSRN: <https://ssrn.com/abstract=2290685>. DOI: 10.2139/ssrn.2290685. [Accessed 03 November 2019].

Song, C. and Oh, W., 2015. Determinants of innovation in energy intensive industry and implications for energy policy. *Energy Policy*, [e-journal] 81, pp.122-130. DOI: 10.1016/j.enpol.2015.02.022.

Sorokin, A.E. and Novikov, S.V., 2019. Formation of the national economy of Russia in the context of state support of innovation actions. *Espacios,* 40(38), pp.4-8.

Sosnowski, J., 2014. Precipitating innovations by academia and industry feedback. *Procedia – Social and Behavioral Sciences,* [e-journal] 109, pp.113-119. DOI: 10.1016/j.sbspro.2013.12.429.

Stefan, I. and Bengtsson, L., 2017. Unravelling appropriability mechanisms and openness depth effects on firm performance across stages in the innovation process. *Technological Forecasting & Social Change,* [e-journal] 120, pp.252-260. DOI: 10.1016/j.techfore.2017.03.014.

Sun, M.Y., Mitra, M.P. and Simone, M.A., 2013. *The driving force behind the boom and bust in construction in Europe.* [Working paper No. 13-181]. Washington, USA: International Monetary Fund. Available at: <https://www.imf.org/external/pubs/ft/wp/2013/wp13181.pdf> [Accessed 03 November 2019].

Tafti, S.F., Jahani, M. and Emami, S.A., 2012. Explaining evolutionary trend of strategic planning from traditional economy to innovation economy. *Procedia – Social and Behavioral Sciences,* [e-journal] 58, pp.56-65. DOI: 10.1016/j.sbspro.2012.09.978.

Tsai, K.H. and Liao, Y.C., 2017. Sustainability strategy and eco-innovation: A moderation model. *Business Strategy and the Environment,* [e-journal] 26(4), pp.426-437. DOI: 10.1002/bse.1926.

Tuguskina, G.N., 2019. Regional features of innovative potential. *Creative Economy,* [e-journal] 13(2), pp.239-248. DOI: 10.18334/ce.13.2.39918.

Usov, N.V., Trofimov, O.V., Frolov, V.G., Makusheva, Y.A. and Kovylkin, D.Y., 2018. Assessment of innovative potential of priority industries of Nizhny Novgorod region. *Russian Entrepreneurship,* [e-journal] 19(10), pp.2921-2930. DOI: 10.18334/rp.19.10.39487.

Ustinova, L.N. and Sirazetdinov, R.M., 2017. Innovation potential of an enterprise: essence, structure, evaluation. *Russian Journal of Entrepreneurship,* 18(23), pp.3751-3764.

Wiener, M., Gattringer, R. and Strehl, F., 2018. Participation in inter-organisational collaborative open foresight A matter of culture. *Technology Analysis & Strategic Management,* [e-journal] 30(6), pp.684-700. DOI: 10.1080/09537325.2017.1376045.

ABOUT AUTHORS

Bakyt Melisovna Bayadilova – (B.B) Kazakh Humanitarian Law Innovation University, Kazakhstan, PhD. student, e-mail: bayadilovabak@rambler.ru, Author's ORCID: 0000-0002-2532-3899.

Arsen Damirovich Nassyrkhanov – (A.N.) Almaty Management University "AlmaU", Kazakhstan, PhD. student, e-mail: nassyrkhanovars@rambler.ru, Author's ORCID: 0000-0003-1992-2956.

Elvira Bulatovna Tlessova – (E.T.) Eurasian National University named after L.N. Gumilyov, Assoc. Prof., e-mail: tlessovaelv@rambler.ru, Author's ORCID: 0000-0001-9593-1251.

Lyazzat Zaitkhanovna Parimbekova – (L.P.) Shakarim State University of Semey, Kazakhstan, Candidate of economic sciences, e-mail: parimbekovalya@rambler.ru, Author's ORCID: 0000-0002-3854-5466.

Maigul Kambarhanovna Tolymgozhinova – (M.T.) Shakarim State University of Semey, Kazakhstan, Candidate of economic sciences, e-mail: tolymgozhinovamai@rambler.ru, Author's ORCID: 0000-0003-4433-8225.

Tursynzada Kuangaliyevna Kuangaliyeva – (T.K.) H. Dosmuhamedov Atyrau State University, Kazakhstan, Assoc. Prof., e-mail: kuangaliyevatur@rambler.ru, Author's ORCID: 0000-0003-2202-3281.

AUTHOR CONTRIBUTIONS

B.B. and A.N. – conceptualization; B.B., M.T. and T.K. – validation; A.N. – methodology, investigation, writing-review and editing; E.T. – software, funding acquisition; L.P. – formal analysis; M.T. – resources, supervision, project administration; B.B. – data, writing original draft preparation; T.K. – visualization.

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.

Supplier Performance Management in Context of Size and Sector Characteristics of Enterprises

DOI: 10.12776/QIP.V24I1.1407

Martin Pech, Drahoš Vaněček

Received: 2020-02-26 Accepted: 2020-03-14 Published: 2020-03-31

ABSTRACT

Purpose: The paper deals with the differences of supplier performance management characteristics by different size of the enterprises and sectors of industry.

Methodology/Approach: The research is based on a questionnaire survey carried out in 2016-2019 in 366 enterprises. Four hypotheses were formulated, focused on supplier selection preferences, frequency of supply evaluation, providing feedback to the suppliers about their performance and quality control. The results are analyzed by the tests of Chi-square statistics.

Findings: The results show that the enterprises differ in the criteria of the selection of the supplier, frequency of supply evaluation and providing feedback to the suppliers about their performance according to their sector industry. In terms of the size of the enterprises, differences were found only in the evaluation of suppliers and evaluation feedback. Enterprises did not differ in quality control of the deliveries.

Research Limitation/implication: The results show that quality is the most evaluated criterion in the selection of the suppliers. In the future, the importance of other environmental and Industry 4.0 criteria will grow. It is recommended combining supplier evaluation and reviews with the feedback to the suppliers to improve the performance of the suppliers.

Originality/Value of paper: The study compares the enterprises in terms of their size and industries in the area of supplier performance management characteristics. These criteria are often not mentioned nor compared in other publications.

Category: Research paper

Keywords: quality; suppliers evaluation; quality control; preferences

1 INTRODUCTION

In recent years, the enterprises have had to compete in the magic quadrilateral – time, cost, quality and service, and continually fought for their market place. Quality plays a major role in this area, in terms of criteria relating to the selection and evaluation of the suppliers, relations with the suppliers, quality control and quality improvements resulting from long-term cooperation. By Shalygin (2018), the enterprises prefer to choose a supplier because of the possibility to reduce product costs and to improve product quality. The aim of the enterprises is to establish long-term cooperation, beneficial for both partners and improving the operational processes.

The selection of reliable suppliers is a prerequisite for the successful management of the production process and therefore it is necessary to pay increased attention to it. Today, the enterprises tend to place the reliability first, encouraging the emergence of partnerships. The enterprise must be able to "foster and educate" good suppliers. It means conducting regular evaluations of contracts concluded during the year, at least once a year. The question of the frequency of such evaluation is also closely related to the evaluation of suppliers. The evaluation is based primarily on control of the quality of supplies. Suppliers should be informed about the outcome and results of the evaluation in various ways. The paper deals with the supplier performance management in context of size and sector characteristics of the enterprises.

2 STATEMENT OF A PROBLEM

This section outlines an overview of literature related to the supplier performance management (SPM). Supplier performance management is "the process of evaluating, measuring, and monitoring supplier performance and suppliers' business processes and practices for the purposes of reducing costs, mitigating risk, and driving continuous improvement" (Gordon, 2008, pp.4). SPM include delivery, cost and quality performance measurement (Monczka et al., 2015). We define SPM as a process in which supplier performance is improved by ensuring quality of selection, evaluation, feedback, quality control and other processes to achieve the benefits of business relations.

2.1 Preferences for Selecting Suppliers

The selection of suppliers is one of the most important purchasing management process for many enterprises within the supply chain, including small and medium sized enterprises (Yadav, Sharma and Singh, 2018). Traditional supplier selection process covers the requirements of a single enterprise only. Hovewer, from strategic perspective, the whole supply chain needs and the long-term supplier relations should be considered (Araz and Ozkarahan, 2007).

Historically, the most important factors considered in supplier selection process are related to quality, delivery and price. Dicksons' study (Dickson, 1966) stated that quality, delivery, performance history, warranties and production facilities and capacity are the most important five criteria. Based on his study, Weber, Current and Benton (1991) later compared the selection criteria. Price was the highest-ranked factor, followed by delivery, quality, production facilities and capacity and geographic location. Sonmez (2006) examined the relative importance of the criteria for supplier selection in different industries in the literature that appeared between 1985 and 2005 and concluded that the private sector enterprises do not base their selection decisions solely on the price, and also other criteria are considered. Deshmukh and Chaudhari (2011) compared the supplier selection criteria with older findings and concluded that price, quality, delivery, production facility and capacity and technical capability are still the most ranked. Similarly, Pal, Gupta and Garg (2013) notice that the basic criteria typically utilized for selecting the suppliers include pricing structure, delivery, product quality, and service.

Tahriri et al. (2008) state that after 2003 more attention is given to the qualitative criteria. Zeydan, Colpan and Cobanoglu (2011) prefer combination of both qualitative and quantitative indicators. Kar (2014) pointed out that with the increased complexity more qualitative criteria are popular. Recent studies (Yildiz and Yayla, 2015) show that quality, delivery, cost, price and service were the most important supplier selection criteria. According Mwadulo and Munialo (2019), criteria of selecting suppliers changed over time, but some of the criteria such as cost, quality and delivery performance remain important. Nowadays, the importance of ability to integrate IT systems in context of Industry 4.0 (Vrchota and Pech, 2019) are gradually increasing.

Based on the research, the authors planned to analyze supplier selection preferences by sector industry and enterprise size. Working hypotheses are the following:

H1a: The enterprises differ in preferences for selecting the suppliers according to the sector.

H1b: The enterprises differ in preferences for selecting the suppliers according to the size.

2.2 Frequency of Evaluation of the Suppliers

There are different procedures for evaluating the suppliers in each enterprise, which usually differ in criteria and methods used. Some enterprises evaluate their supplies and manage their performance in a simple way – they just find the right metrics to put on the scorecards (Gordon, 2008). To evaluate the suppliers and the supply chain performance, various metrics are used, such as the SCOR® model (Lima and Carpinetti, 2016), sustainable supplier selection and evaluation framework (Luthra et al., 2017), benchmarking methods (Souliotis, Giazitzi and Boskou, 2017), key performance indicators (Parmenter, 2010) and the evaluation based on balanced scorecard (Thanaraksakul and Phruksaphanrat, 2009). The main objective of supplier evaluation is to anticipate such events that could result in future quality problems. According to ISO 9001:2015 (ISO, 2015) selected suppliers must be evaluated regularly and the frequency of the evaluation determined. The frequency is usually performed once a year, but sometimes it more frequent monitoring may be required. The problem of frequency of suppliers evaluation analyzed Simpson, Siguaw and White (2002).

Frequency of supplier evaluation is the second topic of the research. Our hypotheses are to confirm that there are differences by sector industry and size:

H2a: The enterprises differ in suppliers evaluation frequency according to the sector.

H2b: The enterprises differ in suppliers evaluation frequency according to the size.

2.3 Providing Feedback to the Suppliers about Their Performance

Reporting the evaluation results provide useful information and feedback to the suppliers. By ISO 9001:2015 (ISO, 2015), communication to the suppliers should include controling and monitoring of suppliers performance. It means that the enterprises obtain feedback relating to quality of products, services and results of supplier evaluation. Periodic in-depth performance reviews are the key long-term activities, especially when the enterprise implement the JIT method. These reviews are typically conducted quarterly and monthly (Giunipero, 1990). The suppliers should be provided feedback related to the results of the evaluation, either negative or positive. To avoid the financial and operational issues, the problems with poor supplier performance should be addressed as soon as possible (Monczka et al., 2015). Many enterprises, however, usually only inform their suppliers of negative results or communicate only when they decide to replace the supplier. The inspections of the enterprises are appropriate. Replacement of the inferior suppliers is usually not a solution because the new ones may not be more reliable and the whole cycle may be repeated again. Therefore, the method of selecting suppliers is rather important. Prahinski and Benton (2004) analyze how the suppliers perceive supplier evaluation communication with a producer and providing the feedback.

The difficulty of the feedback may vary by sector industry and enterprise size. So the following hypotheses are tested:

H3a: The enterprises differ in providing feedback to the suppliers according to the sector.

H3b: The enterprises differ in providing feedback to the suppliers according to the size.

2.4 Quality Control of Deliveries

Quality control is an activity in manufacturing of goods or the provision of a service in the required and uniform acceptable quality that allows full customer satisfaction. The main objective of quality control is to prevent production of defective items and scraps (Jain, 2001). Total Quality Management is "the process of designing and maintaining an environment conducive for performance for a group of people working together for attainment of the common objective in time" (Mukherjee, 2006, pp.17). The term "total" refers to the quality of the entire enterprise. Term "quality" include quality of product, services, processes, relationships and term "management" point out the managing and control processes to fulfil desired customer needs. Quality management use the statistical control techniques for detect deviations from quality standards. Mutual trust between the enterprises often leads to the fact that the customer does not check the quality of the supplies, possibly only at random, and relies on the supplier to always have done it. This also speeds up the manufacturing process. Regular suppliers have the certainty of selling their products for several years, however for such advantage they must strive to gradually reduce their prices.

In case of quality control, the authors tested the differences between industry and enterprises size. The working hypotheses are as follows:

H4a: The enterprises differ in the way they realize quality control of their suppliers according to the sector.

H4b: The enterprises differ in the way they realize quality control of their suppliers according to the size.

3 METHODOLOGY

The main aim of the paper is to analyze the differences in supplier performance management characteristics according to different enterprise size and sectors of industry. In 2016-2019, the authors carried out a questionnaire survey in 366 enterprises. The questionnaire focuses on five main groups of SPM characteristics: preferences for selecting suppliers, frequency of suppliers evaluation, providing feedback to the suppliers, and quality monitoring of deliveries. The research was processed according to two viewpoints:

- by sector (specialization) of the industry (classified by CZ-NACE) into: 1. Engineering and electro-technical production (CZ-NACE groups 24-30), 2. Production of products for domestic use (CZ-NACE Groups 13-16, 31-32; households supply), 3. Food production industry (CZ-NACE Groups 10-12), 4. Chemical, paper and non-metallic production (CZ-NACE groups 17-23), 5. Agriculture (CZ-NACE groups 01-03);
- by enterprise size (according to the number of employees) into: small enterprises (up to 49 employees), 2. Medium enterprises (50-249 employees) and 3. Large enterprises (over 250 employees).

More than half of the enterprises concerned mechanical engineering enterprises (51.1%), household goods made up 15.6% and food businesses 14.2%. The other two fields (Chemical, Agricultural) are represented only in some years (Table 1).

Table 1 – Research Sample Characteristics (2016-2019) (Source: Author's Own Work)

Group	Category of enterprises	Number	Total
Sector	Engineering and electro-technical production	187	*366*
	Household supplies (next only household)	57	
	Food production industry	52	
	Chemical, paper and non-metallic production	49	
	Agriculture	21	
Size	Small (1-49 employees)	126	*366*
	Medium (50-249 employees)	128	
	Large (over 250 employees)	112	

The two-sided hypotheses were tested by the statistical analysis in software R based on the test of equal or given proportions (z-test) with the Yates continuity correction (Pearson's chi-squared test statistic). The results are interpreted at alpha level 0.05. For reasons of clarity, only the significant results, including achieved level of significance (p-value), are given in the text.

$$z = \frac{p_A - p_B}{\sqrt{pq/n_A + pq/n_B}} \qquad (1)$$

Where p_A is the proportion observed in group A with size n_A, p_B is the proportion observed in group B with size n_B p and q are the overall proportions.

4 RESULTS

The results of the analysis are summarised and divided into four parts according to the working hypotheses.

4.1 Preferences for Selecting Suppliers

The authors tested the factors playing the most decisive role in the process of selecting suppliers (quality, price, speed of deliveries etc.). It was possible to use three-point scoring (1 = low importance, 2 = middle, 3 = very important). For better overview, only the preferences scores are presented. As reported by Table 2, all the enterprises prefer reliability of the delivered items, followed by the quality. The price is scored as the third most important. Currently, less emphasize is surprisingly given to speed of delivery and services, in spite of, that both of these two factors offer a considerable advantage in competition.

Table 2 – Preferences for Selecting Suppliers (%) (Source: Author's Own Work)

Category	**Quality**	**Price**	**Speed**	**Reliability**	**Services***
Engineering and electro-technical production	28.2	15.8	15.3	30.7	10.0
Household supplies	30.6	16.5	12.4	30.6	9.9
Food production industry	28.9	18.4	16.7	27.2	8.8
Chemical, paper and non-metallic production	26.1	15.2	15.2	32.6	10.9
Agriculture	27.9	26.2	9.8	26.2	9.8
Small (1-49)	27.4	18.1	12.5	32.7	9.3
Medium (50-249)	28.7	17.5	15.7	28.3	9.8
Large (over 250)	29.4	15.2	16.0	29.0	10.4

Notes: *Services include activities such as: timely provision of information, suitable before and after sales services, flexibility to customer wishes, past experience with suppliers, their proposals to any improvement in cooperation.

The same preferences are revealed as according to the industry sectors, as reported by the second part of Table 2, with the same factors grouped according to the enterprise size (number of employees). The results seem to be very similar as without the preference of the enterprise size.

H1a: The differences between the sectors were statistically proved only for the price (p-value = 0.0030), in particular between agriculture and engineering (p-value = 0.0055) and agriculture and chemical production (p-value = 0.0055). This implies the importance of differences in the sectors by the price only.

H1b: No differences were found by the size of enterprises.

4.2 Frequency of Evaluation of the Suppliers

Regular evaluation of the suppliers in the time interval of one year and less is the requirement for creating good partnership. Surprisingly, many enterprises do not perform any periodic evaluation, see Table 3.

H2a: The differences between the sectors of industry were statistically proven for the annual and longer evaluation frequency (p-value = 0.0071) *and for the evaluation without regular frequency* (p-value = 0.0003). Through a deeper pairwise analysis, it was found that enterprises that do not regularly evaluate their suppliers are mostly agricultural. These differences are particularly significant when compared agriculture to food production (p-value = 0.0323), chemical production (p-value = 0.0323) and engineering and electro technical production (p-value = 0.0084).

Table 3 – Frequency of Suppliers' Evaluation (%) (Source: Author's Own Work)

Category	**1x per year and longer**	**Every 6 months**	**Quarterly**	**No regular evaluation**
Engineering and electro-technical production	42.2	17.1	16.0	24.6
Household supplies	23.2	16.1	16.1	44.6
Food production industry	30.8	21.2	25.0	23.1
Chemical, paper and non-metallic production	42.9	22.4	12.2	22.4
Agriculture	14.3	9.5	14.3	61.9
Small (1-49)	27.8	15.1	16.7	40.5
Medium (50-249)	35.2	17.2	17.2	30.5
Large (over 250)	46.8	21.6	16.2	15.3

H2b: The differences by the size of enterprises were found in annual and longer evaluation frequency (p-value = 0.0092) *and in the case of enterprises not evaluating their suppliers* (p-value = 0.0001). In the annual evaluation, this difference is apparent between the small and the large enterprises (p-value = 0.0110). It is clear that, in particular, the small enterprises do not carry out any regular evaluation.

Overall, the sectors and the size of the enterprise are relevant for one-year and longer frequency of evaluation and for the evaluation without regular frequency.

4.3 Providing Feedback to the Suppliers

It is important to provide the suppliers the feedback so that they could react promptly. A discovered imperfection must be removed by means of mutual meetings, and inspections. It is not convenient to try replace the supplier quickly, when the producer is not satisfied. With a new one the situation might repeat. For this reason, it is necessary to "foster and educate" the suppliers, tell them the deficiency in their activities. There is always a possibility of improvement in this area, when only 10-20 % of suppliers are not familiarized with their results (Table 4). The best situation is in the Engineering and Electro-industry.

H3a: The results show that the differences between enterprises operating in different sectors are important for providing feedback to the suppliers (p-value = 0.0164) and *in case of their replacement* (p-value = 0.0038). Replacement is the start of the process of selecting a new supplier. In this case, it the most important differences in pairwise comparison are found between the chemical industry and agriculture (p-value = 0.045). Overall, the impact of the industry is primarily on providing complete feedback to the suppliers and during their replacement.

Table 4 – Providing Feedback to the Suppliers (%) (Source: Author's Own Work)

Category	**Complex results**	**Negative results only**	**Only when replace**	**No feedback**
Engineering and electro-technical production	43.5	29.3	16.8	10.3
Household supplies	25.5	32.7	30.9	10.9
Food production industry	21.6	37.3	23.5	17.6
Chemical, paper and non-metallic production	38.3	31.9	10.6	19.1
Agriculture	30.0	10.0	45.0	15.0
Small (1-49)	24.4	28.5	28.5	18.7
Medium (50-249)	35.5	28.2	21.8	14.5
Large (over 250)	50.0	34.5	10.9	4.5

H3b: When comparing the evaluation results according to the size of the enterprises, similar results were found, i.e. the differences are in providing complete feedback to the suppliers (p-value = 0.0003) and *in case of their replacement* (p-value = 0.0041). The significant difference was primary between the large and small sized enterprises. In addition, differences were also found if enterprises did not acquaint their suppliers with the evaluation results (p-value = 0.0045). This is particularly evident when comparing large and small enterprises (p-value = 0.0055) or medium-sized (p-value = 0.0389). Obviously, the large enterprises usually inform their suppliers about the results of the evaluation process. The results revealed that the size of an enterprise affects the way in which the enterprises provide the feedback to the suppliers.

4.4 Quality Monitoring of Deliveries

The access to quality monitoring also worth mentioning: Electro-industry monitors the deliveries regularly, engineering randomly and food processing industry prefers trusting to its suppliers (Table 5). The statistical analysis failed to confirm any significant differences in quality monitoring, both in terms of different sectors of industry (*H4a*) and the size of the enterprise (*H4b*). In conclusion, the approach of the enterprises to quality monitoring is similar, regardless of their size or the industry in which they operate.

Table 5 – Quality Monitoring of Deliveries (%) (Source: Author's Own Work)

Category	Regularly	Randomly	Sometimes*	Other
Engineering and electro-technical production	70.0	20.9	6.4	2.7
Household supplies	73.0	21.6	5.4	0.0
Food production industry	77.4	16.1	6.5	0.0
Chemical, paper and non-metallic production	69.6	17.4	0.0	13.0
Agriculture	64.3	14.3	7.1	14.3
Small (1-49)	74.3	14.3	8.6	2.9
Medium (50-249)	72.4	21.1	5.3	1.3
Large (over 250)	66.7	23.2	2.9	7.2

Notes: * "sometimes" means that enterprises trust their main suppliers and check several deliveries only.

5 DISCUSSION

This section outlines the results of the study. The key findings are discussed, and recommendations are provided for the future research. The results show that the reliability and quality are most important criteria in the selection of suppliers. Pernica (2004) states that logistics services include, in particular, reliability of delivery, completeness of supply, reasonable (short) delivery times, pre- and post-sale services provided, quality of distribution and provision of information. For production consumption, the weight of reliability is significantly higher. The importance of reliability is not so obviously discussed in foreign studies. It is the quality that is considered as the most important criterion. For example, Tan, Lyman and Wisner (2002) suggest quality, service level, on-time delivery, quick response and volume flexibility as the critical factors in evaluating supplier performance. Correct quantity and willingness to change products and price are also necessary. Ho, Xu and Dey (2010) gathered and analyzed the most popular evaluating criterion in literature from 2000 to 2008. About 87.18% of all the papers consider quality to be the most important criterion in selecting a supplier. This occurs more frequently as expected because enterprises want to satisfy the customer. According Abdolshah (2013) one of the most important criterion is quality which could integrate more factors to the evaluation. The meaning of the term "quality" may thus be broader and include reliability, which may not be perceived as a different criterion. Therefore, it would be appropriate for the authors to always specify and define the term "quality" in more details. This, in principle, can give rise to possibility of better comparison of studies.

5.1 Sector Industry

From a sectoral perspective, the research results indicate that the enterprises differ in the criteria for selecting their suppliers (*H1a*). The enterprises perceive the importance of prices differently, especially in agriculture. The ideal criteria of supplier selection in food processing industry are defined by Ramlan et al. (2016). They investigated that cost, quality, service and delivery are the most important criteria. The industry was also significant in comparing suppliers' evaluation frequency (*H2a*). It was found in particular, that the agricultural holdings do not carry out a regular evaluation. By Simpson et al. (2002), the frequency of the routine evaluation varied in most of the cases (59.5%). They concluded that the suppliers are usually evaluated after each shipment (2.3%), monthly (15.5%), quarterly (13.3%), semi-annually (6.7%) and annually (13.3%). Similarly, Watts and Hahn (1993) noticed that about 75.3% of the enterprises perform the evaluation of suppliers regularly, 6.9% after every order, 10.3% every three months, 8.6% every six months and 44.8% every twelve months, other 29.3%. These studies do not mention any differences by industry. Furthermore, in our research, the differences between the sectors are identified in providing feedback to the suppliers (*H3a*), particularly in replacing the suppliers, especially in agriculture. The sector of industry was also particularly important in the general results survey in the household and food production, where the suppliers are provided less feedback of the complete results. The enterprises approach to quality monitoring is similar regardless the industry (*H4a*).

5.2 Enterprise Size

The results show, that no differences between the enterprises of different size were found in the criteria for selecting suppliers (*H1b*) and in the quality monitoring method (*H4b*). The size of the enterprise was significant in the evaluation of suppliers (*H2b*) in the case of annual and longer frequency evaluations, and also for the evaluation of the suppliers without a regular frequency. While the large enterprises prefer a one-year or longer evaluation period, the small enterprises do not carry out any evaluation. By Vanecek (2013), the selection process is important only for 36.8% of the small and medium sized enterprises and evaluation process for 25.4% of them. In the study of Su and Gargeya (2016), the small and medium-sized enterprises carry out supplier selection mostly related to the product quality, strategic factors and supplier responsiveness. Pearson and Ellram (1995) compared the frequency of evaluation of the suppliers between the small and the large enterprises. The results show that ad hoc evaluation at buyers' discretion is 35.6% in the small enterprises, and 17.9% in the large enterprises. Review of performance every year and more frequent 33.3% in the small enterprises and 57.7% in the large enterprises. The results of the overall evaluation are then more frequently (*H3b*) communicated to their suppliers by the large enterprises, when the suppliers are replaced. The difference in evaluation frequency can be attributed to a number of factors. Firstly, there is a lack of workers and absence of a quality department in small enterprises. Another problem may be implementation of strategy (if any) or efficiency of the management system. It is difficult to say if these are the underlying factors of overall performance. Ghadimi et al. (2016) believe that the small manufacturing enterprises try to improve their competitive advantage by increasing their commitment in being environmentally and socially responsible, increasing their chance to be selected as a supply partner for a large manufacturing organisation. The competitive advantages of small enterprises are different from those of large enterprises.

6 CONCLUSION

Quality approach to supplier performance management has increased in importance during the last decades. Many enterprises have a supplier quality management function with performance management processes. The paper deals with the evaluation of supplier performance management s on the basis of two criteria: sector industry and enterprise size.

The results show that enterprises differ in terms of sector industry in particular in the criteria of supplier selection, frequency of supplier evaluation and providing feedback to the suppliers. When comparing supplier performance management, the enterprises differ only in frequency of supplier evaluation and use of suppliers evaluation feedback. On the other hand, it is not shown that the the enterprises differ in the way of quality monitoring as regards the size of the enterprise and the sector in which they operate.

First, the authors recommend using top rated selection criteria such as quality (including reliability) and new environmental and technological criteria in the supplier selection process too. Preferences of selecting criteria may change over time, especially in fourth era of the industrial revolution, which is characterized by Industry 4.0, globalization, digitalization and information technology, robotics, the global supply chains and new environmental requirements.

Second, the authors suggest that supplier evaluation and reviews with feedback are combined. The objective for evaluating the suppliers is to improve their performance. Training, consulting and assistance are the most important challenges of supplier sustainable continuous-development. Implementation of sustainable changes and development projects brings long-term benefits, higher quality and comprehensive performance improvement.

The contribution of the research in the paper is mainly related to confirming the increasing importance of human factor in production. Reliability, consisting primarily of adherence to agreed contracts, is assessed by the enterprises as important as quality, which is viewed more technical. The human factor then influences the regularity of suppliers' evaluation, and the lack of familiarization with the overall evaluation, especially in the small and medium-sized enterprises.

ACKNOWLEDGEMENTS

This paper was supported by the University of South Bohemia in Ceske Budejovice under EF-IGS2020-Pech-5 Grant "Industry 4.0 and Supply Chain Management".

REFERENCES

Abdolshah, M. 2013. A Review of Quality Criteria Supporting Supplier Selection. *Journal of Quality and Reliability Engineering*, [e-journal] 2013, pp. 1-9. DOI: 10.1155/2013/621073.

Araz, C. and Ozkarahan, I., 2007. Supplier evaluation and management system for strategic sourcing based on a new multicriteria sorting procedure. *International Journal of Production Economics,* [e-journal] 106(2), pp.585-606. DOI: 10.1016/j.ijpe.2006.08.008.

Deshmukh, A.J. and Chaudhari, A.A., 2011. A Review for Supplier Selection Criteria and Methods. In: K. Shah, V.R.L. Gorty and A. Phirke, eds. 2011. *Technology Systems and Management*. Berlin, Heidelberg: Springer. pp.283-291. DOI: 10.1007/978-3-642-20209-4_41.

Dickson, G.W., 1966. An Analysis Of Vendor Selection Systems And Decisions. *Journal of Purchasing,* [e-journal] 2(1), pp.5-17. DOI: 10.1111/j.1745-493X.1966.tb00818.x.

Ghadimi, P., Azadnia, A.H., Heavey, C., Dolgui, A. and Can, B., 2016. A review on the buyer-supplier dyad relationships in sustainable procurement context: past, present and future. *International Journal of Production Research,* [e-journal] 54(5), pp.1443-1462. DOI: 10.1080/00207543.2015.1079341.

Giunipero, L.C., 1990. Motivating and Monitoring JIT Supplier Performance. *Journal of Purchasing and Materials Management,* [e-journal] 26(3), pp.19-24. DOI: 10.1111/j.1745-493X.1990.tb00508.x.

Gordon, S.R., 2008. *Supplier evaluation and performance excellence : a guide to meaningful metrics and successful results*. Ft. Lauderdale, FL: J. Ross Pub.

Ho, W., Xu, X.W. and Dey, P.K., 2010. Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Journal of Operational Research,* [e-journal] 202(1), pp.16-24. DOI: 10.1016/j.ejor.2009.05.009.

ISO, 2015. *The ISO 9001:2015 Quality management systems - Requirements*. Geneva: ISO.

Jain, P.L., 2001. *Quality Control and Total Quality Management*. New York: McGraw-Hill Education.

Kar, A.K., 2014. Literature Review of Supplier Selection Criteria. *Business Frontiers,* [e-journal] 8(1), pp.1-10. DOI: 10.13140/2.1.1503.3924.

Lima, F.R. and Carpinetti, L.C.R., 2016. Combining SCOR (R) model and fuzzy TOPSIS for supplier evaluation and management. *International Journal of Production Economics,* [e-journal] 174, pp.128-141. DOI: 10.1016/j.ijpe.2016.01.023.

Luthra, S., Govindan, K., Kannan, D., Mangla, S.K. and Garg, C.P., 2017. An integrated framework for sustainable supplier selection and evaluation in supply chains. *Journal of Cleaner Production,* [e-journal] 140, pp.1686-1698. DOI: 10.1016/j.jclepro.2016.09.078.

Monczka, R.M., Handfield, R., Giunipero, L. and Patterson, J., 2015. *Purchasing and Supply Chain Management*. Cincinnati, Ohio: South-Western College Learning.

Mukherjee, P.N., 2006. *Total Quality Management*. New Delphi: PHI Learning.

Mwadulo, M.W. and Munialo, S.W., 2019. Supplier evaluation and Selection. A review. *Journal of Computer & Information Technology,* [e-journal] 10(1), pp.1-6. DOI: 10.22147/jucit/100101.

Pal, O., Gupta, A.K. and Garg, R.K., 2013. Supplier Selection Criteria and Methods in Supply Chains: A Review. *Zenodo*, [e-journal] (Sep), pp.1-7. DOI: 10.5281/zenodo.1088140.

Parmenter, D., 2010. *Key performance indicator: Developing, implementing, and using winning KPIs*. 2nd edition. New Jersey: John Wiley & Sons.

Pearson, J.N. and Ellram, L.M., 1995. Supplier selection and evaluation in small versus large electronics firms. *Journal of Small Business Management*, [e-journal] 33(4), pp.53-65.

Pernica, P., 2004. *Logistika pro 21. století (Supply Chain Management). 3. díl.* Praha: Radix.

Prahinski, C. and Benton, W.C., 2004. Supplier evaluations: communication strategies to improve supplier performance. *Journal of Operations Management,* [e-journal] 22(1), pp.39-62. DOI: 10.1016/j.jom.2003.12.005.

Ramlan, R., Abu Bakar, E., Mahmud, F. and Ng, H.K., 2016. The Ideal Criteria of Supplier Selection for SMEs Food Processing Industry. In: T. Deaconescu and A. Deaconescu, eds., *2016 3rd International Conference on Manufacturing and Industrial Technologies*. Istanbul, Turkey, 25-27 May 2016. Cedex A: EDP Sciences. pp.1-5. DOI: 10.1051/matecconf/20167005006.

Shalygin, M.G., 2018. Method of Supplier Selection by Means of Correlation of Quality and Cost Characteristics of Products. *Quality Innovation Prosperity*, [e-journal] 22(3), pp.27-35. DOI: 10.12776/QIP.V22I3.1189.

Simpson, P.M., Siguaw, J.A. and White, S.C., 2002. Measuring the Performance of Suppliers: An Analysis of Evaluation Processes. *Journal of Supply Chain Management,* [e-journal] 38(4), pp.29-41. DOI: 10.1111/j.1745-493X.2002.tb00118.x.

Sonmez, M., 2006. *A review and critique of supplier selection process and practices*. Loughborough University, Business School. Available at: <https://repository.lboro.ac.uk/ndownloader/files/17121305/1> [Accessed 19 January 2020].

Souliotis, A., Giazitzi, K. and Boskou, G., 2017. Benchmarking between vegetable suppliers in Greece. *Benchmarking-an International Journal,* [e-journal] 24(6), pp.1649-1662. DOI: 10.1108/bij-05-2016-0071.

Su, J. and Gargeya, V.B., 2016. Supplier selection in small- and medium-sized firms The case of the US textile and apparel industry. *American Journal of Business,* [e-journal] 31(4), pp.166-186. DOI: 10.1108/ajb-12-2015-0037.

Tahriri, F., Osman, M.R., Ali, A. and Yusuff, R.M., 2008. A review of supplier selection methods in manufacturing industries. *Suranaree Journal of Science and Technology,* 15(3), pp.201-208.

Tan, K.C., Lyman, S.B. and Wisner, J.D., 2002. Supply chain management: a strategic perspective. *International Journal of Operations & Production Management,* [e-journal] 22(5-6), pp.614-631. DOI: 10.1108/01443570210427659.

Thanaraksakul, W. and Phruksaphanrat, B., 2009. Supplier Evaluation Framework Based on Balanced Scorecard with Integrated Corporate Social Responsibility Perspective. In: IAENG (International Association of Engineers), *IMECS 2009 International Multi-Conference of Engineers and Computer Scientists*. Hong Kong, Hong-Kong, 18-20 May 2009. pp.1929-1934.

Vanecek, D., 2013. The approach of small and medium sized enterprises to process management. *Acta Universitatis Bohemiae Meridionales,* [e-journal] 16(1), pp.25-34.

Vrchota, J. and Pech, M., 2019. Readiness of Enterprises in Czech Republic to Implement Industry 4.0: Index of Industry 4.0. *Applied Sciences,* [e-journal] 9(24), pp.1-25. DOI: 10.3390/app9245405.

Watts, Ch.A. and Hahn, Ch.K. 1993. Supplier Development Programs: An Empirical Analysis. *International Journal of Purchasing and Materials Management*, [e-journal] 29(1), pp.10-17. DOI: 10.1111/j.1745-493X.1993.tb00002.x.

Weber, C.A., Current, J.R. and Benton, W.C., 1991. Vendor selection criteria and methods. *European Journal of Operational Research,* [e-journal] 50(1), pp.2-18. DOI: 10.1016/0377-2217(91)90033-R.

Yadav, V., Sharma, M.K. and Singh, S., 2018. Intelligent evaluation of suppliers using extent fuzzy TOPSIS method: A case study of an Indian manufacturing SME. *Benchmarking-an International Journal,* [e-journal] 25(1), pp.259-279. DOI: 10.1108/bij-07-2016-0114.

Yildiz, A. and Yayla, A.Y., 2015. Multi-criteria decision-making methods for supplier selection: A literature review. *South African Journal of Industrial Engineering,* [e-journal] 26, pp.158-177. DOI: 10.7166/26-2-1010.

Zeydan, M., Colpan, C. and Cobanoglu, C., 2011. A combined methodology for supplier selection and performance evaluation. *Expert Systems with Applications,* [e-journal] 38(3), pp.2741-2751. DOI: 10.1016/j.eswa.2010.08.064.

ABOUT AUTHORS

Martin Pech – (M.P.) University of South Bohemia in Ceske Budejovice, Czech Republic, Faculty of Economics, Department of Management, Asst. Prof., e-mail: mpechac@ef.jcu.cz, Author's ORCID: 0000-0002-0807-3613.

Drahoš Vaněček – (D.V.) University of South Bohemia in Ceske Budejovice, Czech Republic, Faculty of Economics, Department of Management, Prof., e-mail: dvanecek@ef.jcu.cz, Author's ORCID: /0000-0003-2767-2686.

AUTHOR CONTRIBUTIONS

M.P. and D.V. – conceptualization, investigation, resources, writing original draft preparation, writing review and editing; M.P. – methodology, software, formal analysis, data curation, visualization, project administration, funding acquisition; D.V. – validation, supervision.

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.

Implementation of Statistical Process Control through PDCA Cycle to Improve Potential Capability Index of Drop Impact Resistance: A Case Study at Aluminum Beverage and Beer Cans Manufacturing Industry in Indonesia

DOI: 10.12776/QIP.V24I1.1401

Sunadi Sunadi, Humiras Hardi Purba, Sawarni Hasibuan

Received: 2020-02-17 Accepted: 2020-03-10 Published: 2020-03-31

ABSTRACT

Purpose: The purposes of this study are first, to analyze why the *process capability index* (*Cpk*) for drop impact resistance (DIR) does not meet the specification or less than 1.33, and second, to find out what improvements should be made to make it meet the specification.

Methodology/Approach: The methodology used was Statistical Process Control (SPC) through the PDCA cycle, supporting with Cause and Effect Diagram (CED), Nominal Group Technique (NGT) and "why, what, where, when and how (5W1H)" method.

Findings: With the above methods, the result of the study was given a positive impact on the company. The average of DIR was increased from 20.40 cm to 25.76 cm, increased by 26.27% and the standard deviation was reduced from 1.80 to 1.48, and then the *Cpk* index was increased from 0.48 to 1.79 it means the process is in control and capable.

Research Limitation/implication: This research was limited only on the two-piece can aluminum cans manufacturing process, no for three-piece cans manufacturing. SPC through PDCA cycle is an interesting method for continuous improvement of process capability in the cans manufacturing industry.

Originality/Value of paper: This study highlights the area of future research SPC through the PDCA cycle to analyze and optimize process capability. Therefore, this research is considered to promote and adopt high-valued methodologies for supporting industry to achieve global competitive advantages.

Category: Case study

Keywords: drop impact resistance; SPC; *Cpk*; PDCA; 5W1H

1 INTRODUCTION

The Canmaker Magazine Vol 32: February 2019 reported that the beverages cans demand in the Southern East Asia region is about 7.2% from the total 335 billion of the global beverages cans demand. Aluminum cans have experienced many important developments throughout the years, if compared with other packaging aluminum cans having some advantages such as good in the stackable, easy opening by full the tab, hermetic sealing, environmental and economic (Mohamed, 2016).

With all these advantages and a good trend in the market, that condition redirects in progressively savage challenges to get each other's chances. Aluminum beverages cans manufacturing industry located in Jakarta is one of the packaging industry in Indonesia that has engaged with the challenge to become the cost leader and also to remain competitive in the global world packaging industry today, with slightly process changes in tooling geometry of punch sleeve and activated oven washer dryer zone 2 to achieve the minimum requirement of the potential capability to be able to produce the aluminum beverages cans with the new aluminum raw materials (Y1) without any reducing or degradation of the aluminum cans product quality.

The fact was with Y_1 material; from nine critical parameters, there is anyone of them the potential *capability index (Cpk)* does not meet the minimum requirement, the parameter is DIR with the *Cpk* index achievement was 0.48. The investigation intends to get the reasons for the faulty. Statistical Process Control (SPC) through the PDCA cycle and *Nominal Group Technique (NGT)* are combining in utilized to find out the root cause and the 5W1H method was used for improvement determinations. As one of the facts in the real industry that the defected of the products can be reduced effectively by the Integrating of nominal group technique, Shainin system, and DMAIC methods (Trimarjoko et al., 2019).

Quality improvement is becoming a critical issue in the highly competitive business environment nowadays, so the products are made need to be upgraded regularly (Dhounchak and Biban, 2017). Minimizing defects during the process is one thing that needed to maintain customer loyalty (Realyvásquez-Vargas et al., 2018). To make high-quality products proper planning and preparation are categorized as a vital factor (Chakraborty, 2016). The organization needs to maintain a process and keeping continuous improvement to make good product quality and minimize defects (Nugroho, Marwanto and Hasibuan, 2017). To reduce defects and minimize process variation can be used in the DMAIC method (Ani, Ishak and Shahrul, 2016). The investigation of a problem and the development of an appropriate solution to the quality improvement process could be able using quality tools (Nabiilah, Hamedon and Faiz, 2018). Many statistical tools are available to improve process; one of them is SPC (Statistical Process Control). SPC could be able to maintain process stability and capability (Saputra et al., 2019). The deviation or variation of the process can be eliminated, and also, the process capability can be increased by applying the DMAIC method (Sharma and Rao, 2013).

In the competitive business environment, the SPC method could be able to use to improve the process (Godina, Matias and Azevedo, 2016). Claim from customer need to be controlled well, SPC is one of the many tools it's effective in reducing claim (Solihudin and Kusumah, 2017). Quality could be able to increase by solving problem happened during the process, and the SPC method can be used as tools (Devani and Wahyuni, 2017). Product quality must be maintained; it can be implemented by building the team to aware of SPC (Mangesha, Singh and Amedie, 2013). Product quality control with the SPC method helps in reducing defects (Supriyadi, 2018). A process could be evaluated effectively by seeing the capability process index, which can be used as a managerial decision (Sagbas, 2009). Identifying the critical to the quality of a machining and prioritization corrective action are strongly needed for the improvement step, and the DMAIC method can be used to increase capability index level (Sharma, Rao and Babu, 2018). Quality satisfaction can be created through statistical tool implementations like SPC and FMEA (Rana, Zhang and Akher, 2018). Control chart standard deviation (S) and ($\bar{X}$)) are a statistical tool which can be used to a created quality products, and it could be able to upgrade to becoming a high-quality product with controlling the range and capability process coefficient as the indicator (Fazeli and Sharifi, 2011). To create a quality of the product are made has to be started from a small issue which was happened on the process or organization (Tuna, 2018). The quality is essential for the product that was made. It can be maintained with SPC implementation as robust tools (Bereman et al., 2014). Quality could be improved by emphasizing all the levels in the company to discipline to use statistical tools (Sokovi, 2009). The organization or company need to be aware to avoid mistake or wrong in doing an operation. QC with 7 tools is a switchable tool (Magar and Shinde, 2014). Also, in anticipating globalization, the product defect must be reduced, Kaizen and PDCA cycle are a famous tool to make it happened (Darmawan, Hasibuan and Hardi Purba, 2018). The organization or company that have many product types, a lot of checked quality parameter and also the materials came from many sources it recommended to implement the assessment process with monitoring stability and capability (Ramirez and Runger, 2006).

2 RESEARCH METHODOLOGY

The study aims to find out the factors were causing *potential capability index* (Cpk) of DIR for aluminum beverages cans does not meet the customer requirement or common industrial standard and constructing the steps of corrective to improve it in minimum 1.33. The conceptual frameworks for this matter are illustrated in Appendix 1 (Figure A1).

Based on research framework as in Figure 1, for getting *potential capability index* (*Cpk*) is meeting to the customer standard, SPC through PDCA cycle with the integration of NGT and 5WIH methods are used, supported with some of the statistical tools such as (X,)̅R chart, histogram, and fishbone diagram.

3 RESULT AND DISCUSSION

Process improvements must be given high priority and documented. By using SPC through the PDCA cycle followed with CED and NGT to identify the root cause, then continued with 5W1H methods for determining improvements, the steps to achieve the above matter as in Figure 1.

Steps/cycle	**Activity**
Plan	Data collection, determine research priority and interview.
D0	Making a plan and do an improvement with the 5W1H method.
Check	Stability process *($\bar{X}$ – R Chart*) and *process capability (Cpk).*
Action	Making standardization.

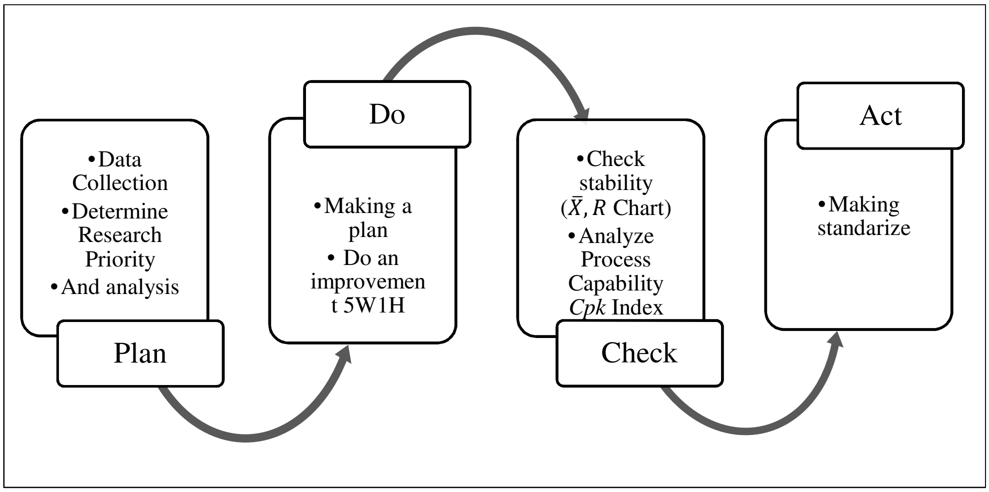


Figure 1 – Steps of the PDCA Cycle

3.1 Data Collections

Table 1 below is data of capability study for nine (9) critical quality parameters after any change on the input aluminum material for packaging aluminum beverages cans manufacture.

Table 1 – The Capability Study Data of Nine Critical Quality Parameters

Items	Sample (n)	Average	Min	Max	Std dev.	*Cp*	*Cpk*
1. Finish can height (mm)	180	146.02	145.87	146.15	0.05	3.04	2.24
2. Flange width (mm)	180	2.09	1.99	2.19	0.04	2.06	1.96
3. Plug Diameter (mm)	60	50.05	50.01	50.10	0.002	3.40	2.50
4. Axial Load (Lbs)	150	227.8	224	232	1.37	NA	12.60
5. Buckle Strength (Psi)	150	96.12	94.4	98.3	0.86	NA	2.35
6. Thin Wall Thickness (mm)	200	0.092	0.09	0.095	0.001	NA	2.01
7. Dome Depth (mm)	300	10.41	10.35	10.46	0.02	3.94	1.96
8. Reform Diameter (mm)	300	44.78	44.76	44.82	0.01	3.92	3.24
9. DIR (cm)	150	20.40	17.80	22.90	1.80	NA	0.48

3.2 Determining Improvement Priority

The capability study data, as in Table 1, concerning the *potential capability index* (*Cpk*), plotting to the trend chart to get easier in the analysis, as shown in Figure 2.

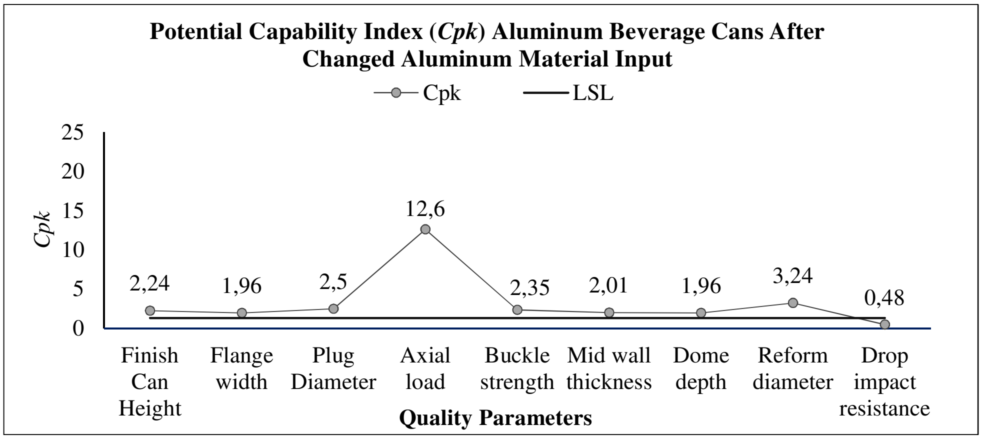


Figure 2 – Trend chart of Potential Capability Index (Cpk) Aluminum Beverages Cans With New Aluminum Raw Materials

Showing up Figure 2 above clearly that the DIR parameter is needed to be improved due to the achievement of the *potential capability index* (*Cpk*) was less than 1.33.

3.3 Discussion in Determining The Root Cause

The discussion was done with the staff of packaging aluminum beverage cans plant in Indonesia consisting of production, corporate production, and the Quality Assurance department. The aim of the discussion is for getting optimum results in solutions. Table 2 is describing the result of the discussion or brainstorming regarding the possibility of the root cause for the faulty drop impact resistance capability with the index less than 1.33.

Table 2 – The Brainstorming Data for the Possibility of the Root Cause for Drop Impact Resistance Aluminum Beverages Cans Faulty in Achievement Cpk Index > 1.33

No.	Causes	Causes Factor	Code
1	Annealing or softening of the aluminum materials	Material	CF1
2	Aluminum material thickness	Material	CF1
3	Washer oven dryer temperature	Machine	CF2
4	Temperature Feco oven decorator	Machine	CF2
5	Temperature oven IBO	Machine	CF2
6	Mat conveyor jam with full cans inside oven dryer washer, Feco oven deco or IBO oven with duration > 5 minutes	Machine	CF2
7	Domer process, the dome depth dimensions	Machine	CF2
8	The aluminum thickness of the dome area	Tooling	CF3
9	Profile / Geometry tooling of punch sleeve	Tooling	CF3
10	Bottom profil reformer, reform diameter dimensions	Machine	CF2
11	Air pressure that injected to inside the cans during testing DIR	Method	CF4
12	Base plate thickness for testing DIR	Method	CF4
13	Operator less knowledge	Man	CF5
14	Mistake or wrong in the measurement	Man	CF5
15	Lack of lighting	Environment	CF6
16	Body maker speed unstable	Machine	CF2
17	SOP not updated	Method	CF4

By observing Table 2, from 17 items of possibilities were causing for DIR does not meet to the customer specification in term of the *Cpk* achievement, to make clear in analysis the next table will be given classification information in more specific and details as stratification. Table 3 is describing the cause of the human (man) factor, the cause of the material factor as in Table 4, the cause of the method factor is in Table 5, the cause of machine factor is in Table 6, the cause of the tooling geometry factor is in Table 7, and the cause of the environment factor is in Table 8.

Table 3 – Cause of a Human (man) Factor

CF5	No.	Potential cause	Causes factor
	1	Operator less knowledge	Man
	2	Wrong in measurement	Man

Table 4 – Cause of Material Factor

CF1	No.	Potential cause	Cause factor
	1	Annealing or softening material aluminum deformation after Washer Dryer (Yield strength deformation)	Material
	2	Thickness of aluminum material	Material

Table 5 – Cause of Method Factor

CF4	No.	Potential cause	Cause Factor
	1	Air pressure was injected into the cans	Method
	2	The thickness of the DIR base plate fixture	Method
	3	SOP not update	Method

Table 6 – Cause of Machine Factor

CF2	No.	Potential cause	Cause Factor
	1	Body Maker speed	Machine
	2	Washer Dryer temperature setpoint	Machine
	3	Feco Oven Decorator temperature setpoint	Machine
	4	IBO Oven temperature setpoint	Machine
	5	Mat Conveyor Washer Oven Dryer, Pin Chain Feco Oven Decorator or Mat Conveyor IBO jam or stopped > 5 minutes.	Machine
	6	Doming Process	Machine
	7	Bottom Profile Reformer machine.	Machine

Table 7 – Cause of Tooling Factor

CF3	No.	Potential Factor	Cause Factor
	1	Punch sleeve tooling geometry	Tooling
	2	The aluminum thickness of the dome area	Tooling

Table 8 – Cause of Environment Factor

CF6	No.	Potential Factor	Cause Factor
	1	Lack of lighting	Environment

From the above stratification data in (Table 3-8), the next step is plotting into the cause and effect diagram (CED) with the aim to determining the root cause of why the potential capability index of drop impact resistance parameter for aluminum beverages cans does not meet to the customer requirement or common industry standard.

3.4 Creating the CED

CED to determining the possible root cause, as shown in Figure 3.

Analyzed CED as in Figure 3, there were ten (10) the possible root cause of the potential *capability index* (*Cpk*) does not meet to the customer requirement as can be seen on the rectangular box with dashed lines, details of the possible root cause are as follows:

(1) Man: The possibility of the operator did wrong or a mistake in measurement and lack of knowledge.

(2) Material: Yield strength and thickness

(3) Method: Air pressure that injected inside the cans and base plate thickness.

(4) Machine: Temperature Oven Washer Dryer; Conveyor Mat Washer Dryer, Feco Oven Deco or IBO Mat Conveyor jam or stopped > 5 minutes.

(5) Tooling: Punch sleeve tooling geometry and Aluminum thickness at dome area.

(6) Environment: Lack of light sources.

Based on the six factors above with ten findings cause were considered as the potential sources of the cause.

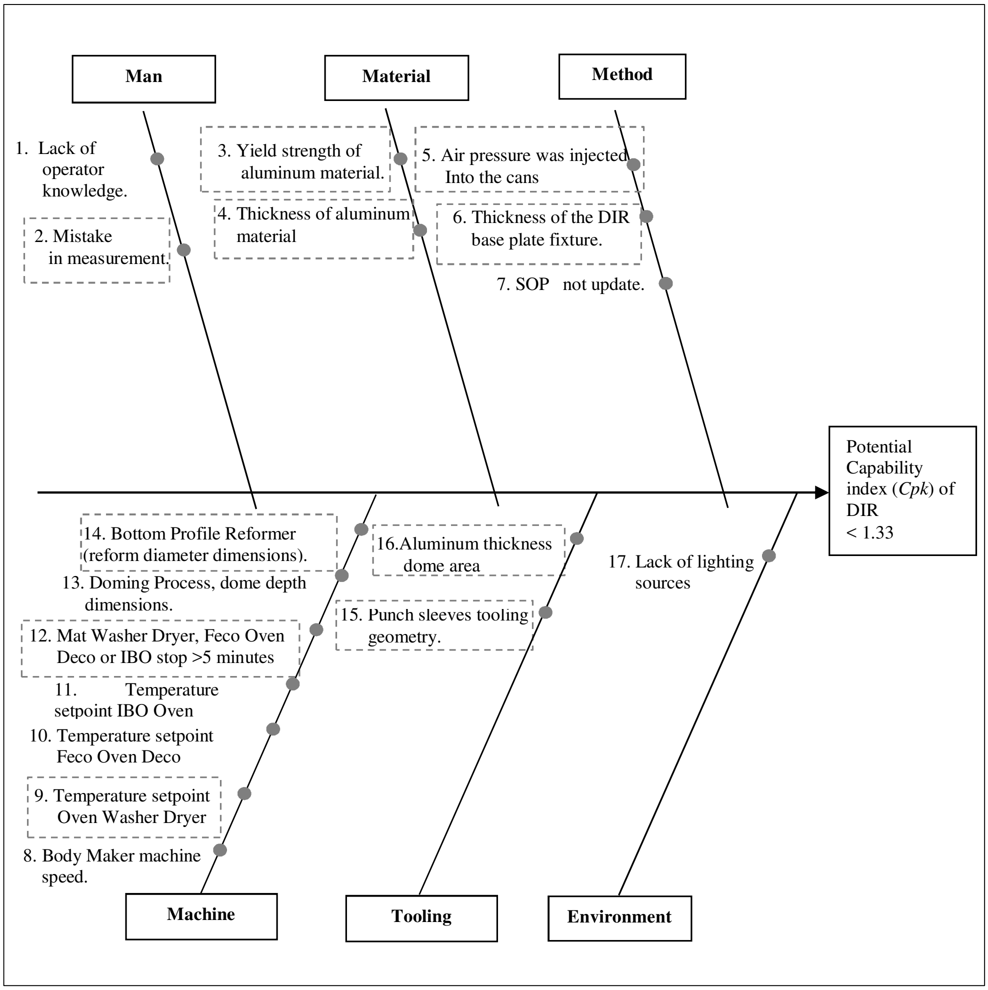


Figure 3 – CED or Fishbone Diagram for DIR Faulty

3.5 Creating the NGT

The next step is determining what the dominant cause for the issue. *NGT* method was used, the discussion group with eight members to involve in giving the score for *NGT*. All the members were coming from different backgrounds such as education, age, year of service, and current expertise. With these differences in the various background, it will be resulted in more accurate in giving the information, and finally, the correct decision is gotten. The concept of it is as in Table 9.

Table 9 – NGT Data Exposure Cause of Cpk below 1.33

No.	Variable Causes	Scorer								Total Score
		Scorer 1	*Scorer 2*	*Scorer 3*	*Scorer 4*	*Scorer 5*	*Scorer 6*	*Scorer 7*	*Scorer 8*	
1	V_1	4	5	5	4	5	6	5	5	39
2	V_2	5	4	6	5	5	5	5	5	40
3	V_3	5	4	5	4	5	5	6	5	39
4	V_4	7	8	7	6	5	8	7	8	56
5	V_5	5	5	4	6	4	5	5	6	40
6	V_6	7	5	5	6	6	7	7	8	51
7	V_7	5	5	5	5	4	5	6	5	40
8	V_8	5	4	5	4	5	6	5	5	39
9	V_9	8	7	8	6	7	8	7	7	58
10	V_{10}	5	5	4	5	5	5	6	5	40

Notes: V_1: Operator wrong measurement, V_2: Aluminum Yield Strength, V_3: Aluminum material thickness, V_4: Air pressure that injected inside the cans for test DIR high fluctuations. , V_5: Baseplate fixture drop impact resistance > 31 mm, V_6: Temperature oven washer dryer too high > 420oF. , V_7: Mat (oven dryer, IBO) and Feco Deco stopped for more than 5 minutes, V_8: Reform diameter dimensional, V_9: Tooling Geometry of punch sleeve and V_{10}: Aluminum thickness dome area.

The NGT calculated based on the below equasion:

$$\mathrm{NGT} \geq \frac{1}{2}\ (\text{Total number of scorer} * \text{Caused Variable}) + 1 \tag{1}$$

$$\mathrm{NGT} \geq \tfrac{1}{2}\ (8 * 10) + 1\text{ , so NGT} \geq 41$$

Interpreted of Table 9 linked to the *NGT* value with using equasion (1) there are three (3) potential variable causes have *NGT* higher or the same 41, that became a dominant factor of the cause for the *Cpk* DIR achievement, namely: Air pressure injected to inside the cans, temperature of oven dryer and tooling geometry of punch sleeve.

3.6 Making Improvements

After the dominant cause or a vital factor is found, the next step is to determine the improvement steps.

3.6.1 Quality Improvement Plan (Plan)

By identifying the underlying causes, clarifying why they need to be improved, what improvements are being made, where or what areas are being corrected, when actions will be taken, who will improve them, and how to improve them, it will be more targeted. More details, improvement plans with the concept 5W1H are described as in Table 10.

Table 10 – Quality Improvement Plan and Action 5W1H

No	Cause	Why	What	Where	When	Who	How
1	Unstable air pressure, which was injected into inside the cans some time more than 60 Psi was observed.	Pressure gauge indicator was broken.	The pointer scale has not precise.	Regulator drop test fixture.	August, 2019	Hadi.P	Changed with the new one.
2.	The temperature setpoint of washer oven dryer too hight > 420ºF.	Only using one zone for drying the cans.	Reducing the temperature to below 420⁰F.	Oven washer dryer.	July, 2019	Farid	Activated oven zone 2 to getting a temperature oven dryer below 420ºF.
3	Profile or geometry tooling of Punch Sleeve.	The clearance needs to be adjusted in matching with new material.	Punch sleeve nose radius.	Punch Nose Radius R_1 dan R_2.	September 2019	Anton	Modifying punch nose radius, R_1 punch nose radius was changed from 0.05 inch to 0.06 inch, and R_2 punch nose was changed from 0.042 inches to 0.05 inch.

3.6.2 Implementation of Quality Improvement (Do)

Air pressure is injected inside the cans before the test of DIR

To avoid air pressure that injected inside the cans before test DIR, the pressure gauge indicator changed to the new one and doing the routine check for the function of pressure gauge with monthly bases and put on the calibration schedule.

Temperature oven washer dryer too high > 420ºF

To make oven washer dryer temperature does not exceed 420ºF the action has been done is activated oven dryer zone 2. Detail temperature with activated zone 2 is, as shown in Table 11.

Table 11 – Details of Oven Washer Dryer Temperature Setpoint

Aluminum Material Thickness	**Zone 1**	**Zone 2**	**Drying Time**
Current Thickness (Y_o)	430°F	Idle	1 minute and 26 seconds.
New Thickness (Y_1)	385°F	395°F	2 minutes and 52 seconds.

In line with the above data on Table 11, by activating two oven zones on the typical washer oven dryer, the oven temperature setpoint can be able to set to 395 °F for two minutes and fifty-two secs. The drying effectiveness has been still good and the particular big impact on the lightweight aluminum is getting safer to avoid annealing or softening if the machine stoppage or perhaps jam for a while. Figure 4 below is illustrated typical of oven washer dryer zone 1 and zone 2.

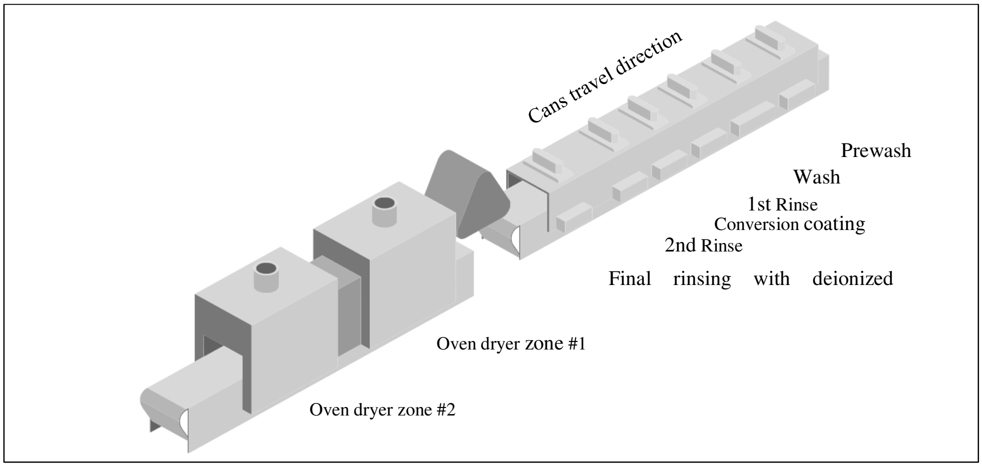


Figure 4 – Washer and Oven Dryer

Tooling Geometry or Profile Punch Sleeve

Stretching aluminum at dome area point 3 (p3), as shown in Figure 5 was reached 3.83% from the original thickness, it resulted in the drop impact resistance became weak.

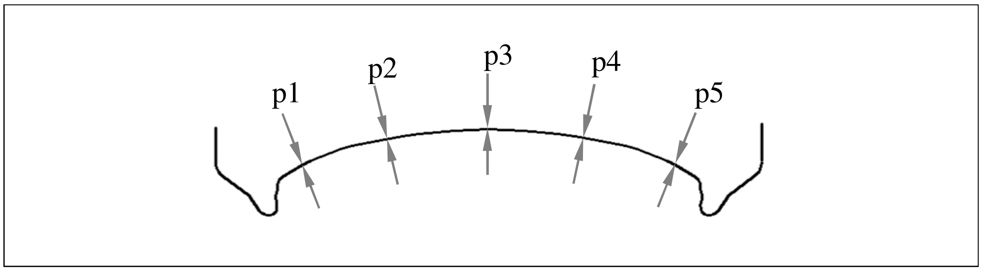


Figure 5 – Measurement Point for Aluminum Thickness Dome Area of Aluminum Beverage Cans

Figure 6 below is describing punch sleeve nose radius schematic radius 1 (R_1) and radius 2 (R_2).

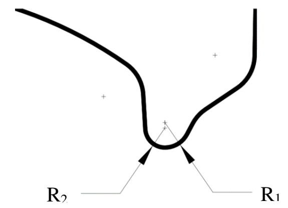


Figure 6 – Schematic of Dome Formation for Aluminum Beverages Cans: R_1: Radius 1, R_2: Radius 2

Changing details of punch sleeve tooling geometry or profile are as shown in Table 12.

Table 12 – The Information of Punch Sleeve Tooling Geometry or Profile Modification

Items	**Before**	**After**
R_1 (Inch)	0.050	0.060
R_2 (Inch)	0.042	0.050

3.7 Constructing $\overline{X}$ and R Chart

$\overline{X}$ and R Chart was used to control process stability with the final purposes is to minimize process variations. The below data as in Table 13 is capability study data for 5 hours running after improvement was done.

The sampling was carried out for 5 hours, from 08:15 a.m. to 12:15 p.m, followed by the DIR test with the air pressure were injected inside the cans continuously controlled at 60 Psi, the results of the test as shown in Table 13 above. From these data, we do the calculation to find the central point or *Center Line (CL), Upper Control Line (UCL),* the carry control point or *Lower Control Limit (LCL)* and its process capability index or *Index Capability Process (Cpk).*

Table 13 – Capability Study Data of DIR for 5 Hours Running on October 03, 2019 (cont's)

Date	**Time**	**Machine**	**i**	**ii**	**iii**	**iv**	**v**	**vi**	$\bar{X}$	**R**
03 Oct, 2019	08:15	1	27.94	25.40	25.40	25.40	27.94	25.40	26.25	2.54
		2	25.40	27.94	25.40	25.40	27.94	25.40	26.25	2.54
		3	27.94	25.40	22.86	25.40	25.40	25.40	25.40	5.08
		4	25.40	25.40	22.86	27.94	25.40	27.94	25.82	5.08
		5	25.40	25.40	25.40	25.40	27.94	27.94	26.25	2.54
	09:15	1	27.40	25.40	27.94	25.40	25.40	25.40	26.16	2.54
		2	25.40	25.40	22.86	25.40	27.94	25.40	25.40	5.08
		3	22.86	25.40	25.40	27.94	25.40	25.40	25.40	5.08
		4	27.94	25.40	25.40	22.86	27.94	25.40	25.82	5.08
		5	25.40	25.40	27.94	25.40	25.40	25.40	25.82	2.54
	10:15	1	25.40	27.40	25.40	27.94	25.40	25.40	26.16	2.54
		2	25.40	27.94	25.40	22.86	25.40	25.40	25.40	5.08
		3	25.40	25.40	25.40	25.40	27.94	25.40	25.82	2.54
		4	25.40	25.40	27.94	25.40	27.94	25.40	26.25	2.54
		5	22.86	25.40	25.40	25.40	27.94	25.40	25.40	5.08
	11:15	1	25.40	25.40	27.94	25.40	25.40	25.40	25.82	2.54
		2	25.40	27.94	22.86	25.40	25.40	25.40	25.40	5.08
		3	25.40	25.40	27.94	25.40	25.40	25.40	25.82	2.54
		4	25.40	25.40	25.40	27.94	22.86	25.40	25.40	5.08
		5	25.40	25.40	22.86	25.40	27.94	25.40	25.40	5.08
	12:15	1	27.94	25.40	25.40	25.40	25.40	25.40	25.82	2.54
		2	22.86	25.40	25.40	25.40	25.40	27.94	25.40	5.08
		3	25.40	25.40	25.40	25.40	27.94	25.40	25.82	2.54
		4	25.40	22.86	25.40	25.40	25.40	27.94	25.40	5.08
		5	27.94	25.40	25.40	25.40	27.94	25.40	26.25	2.54
									$\bar{\bar{X}}$ 25.765	$\bar{R}$ 3.759

3.7.1 The specification of DIR

The specification of DIR is minimum of 17.78 cm

3.7.2 Determining the Centre Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) for X-Chart

Centre Line (CL):

$$\begin{aligned} \mathrm{CL} &= \overline{\overline{\mathrm{X}}} \\ &= 25.765 \end{aligned} \tag{2}$$

Upper Control Limit (UCL):

$$\begin{aligned} \mathrm{UCL} &= \overline{\overline{\mathrm{X}}} + \mathrm{A_2}\overline{\mathrm{R}} \\ &= 25.765 + 0.483(3.759) \\ &= 27.580 \end{aligned} \tag{3}$$

Lower Control Limit (LCL):

$$\begin{aligned} \mathrm{LCL} &= \overline{\overline{\mathrm{X}}} - \mathrm{A_2}\overline{\mathrm{R}} \\ &= 25.765 - 0.483(3.759) \\ &= 23.9494 \end{aligned} \tag{4}$$

3.7.3 Determining control limit CL, LCL and UCL for $\overline{R}$-Chart

Centre Line (CL):

$$\begin{aligned} \mathrm{CL} &= \overline{\mathrm{R}} \\ &= 3.759 \end{aligned} \tag{5}$$

Upper Control Limit (UCL):

$$\begin{aligned} \mathrm{UCL} &= \mathrm{D_4}\overline{R} \\ &= 2.004(3.759) \\ &= 7.533 \end{aligned} \tag{6}$$

Lower Control Limit (LCL):

$$\begin{aligned} \mathrm{LCL} &= \mathrm{D_3}\overline{R} \\ &= 0(3.759) \\ &= 0 \end{aligned} \tag{7}$$

The constant for A2, D3 dan D4 for subgroup number 6 is as in Table 14.

Table 14 – The Control Chart Constants

Sample Size = m	A2	A3	d2	D3	D4
2	1.880	2.659	1.128	0	3.267
3	1.023	1.952	1.693	0	2.574
4	0.729	1.628	2.059	0	2.282
5	0.577	1.427	2.326	0	2.114
6	0.483	1.287	2.534	0	2.004
7	0.419	1.182	2.704	0	1.924

The above calculation on Eq. (2), (3), (4), (5), (6), and (7) plotted to the chart using statistical software NWA Analysis v6.3 with the result as on Figure 7.

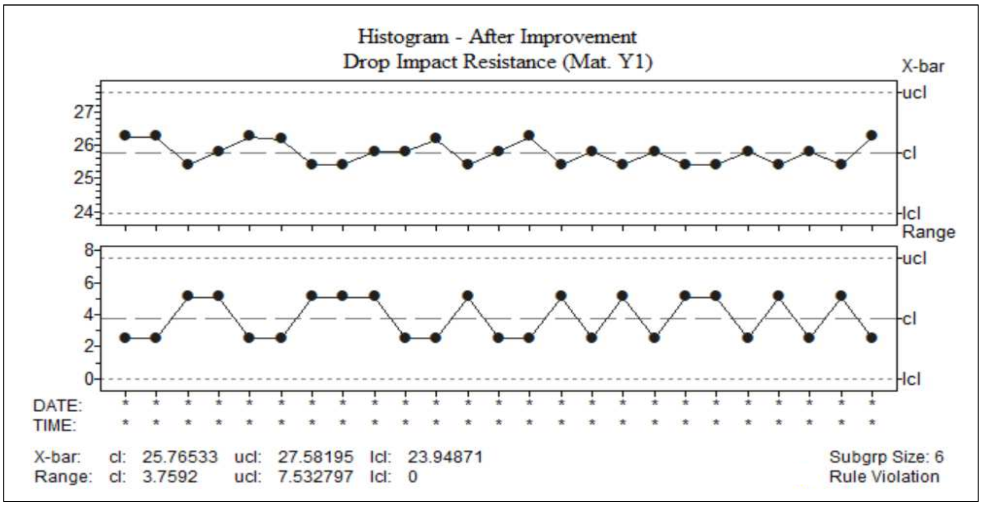


Figure 7 – $\bar{X}$-R Chart Drop Impact Resistance After Improvement of the 3 Dominants Factor

From the control chart in Figure 7, the process statistically was stable; the indication is there was no point is out from the control limit.

3.8 Calculating the Potential Capability Index (*Cpk*)

To calculate the potential capability index firstly need to know the standard deviation, due to the capability index, was decided using *Cpk* on this research so the standard deviation directly can be calculated as estimated standard deviation. The estimated standard deviation could be calculated using the below equation (8).

Determining the standard deviation (s):

$$S = \frac{\bar{R}}{d2} \tag{8}$$

DIR has only had one side specification (minimum specification), and the *Cpk = Minimum (Cpu, Cpl),* due to only one side specification so the *Cpk* will be the same with *Cpl* $(Cpk = Cpl)$. To determining the *Cpk*, the formula used as on (9).

$$Cpk = \frac{(\bar{\bar{X}} - \mathrm{LSL})}{3S} \tag{9}$$

$$Cpk = \frac{(25.765 - 17.78)}{3(\frac{\bar{R}}{d2})} = \frac{(25.765 - 17.78)}{3(\frac{3.759}{2.534})} = 1.79$$

The *Cpk* calculation based on the equation (9) is plotted to the histogram using statistical software NWA Analysis v6.3 with the result as in Figure 8.

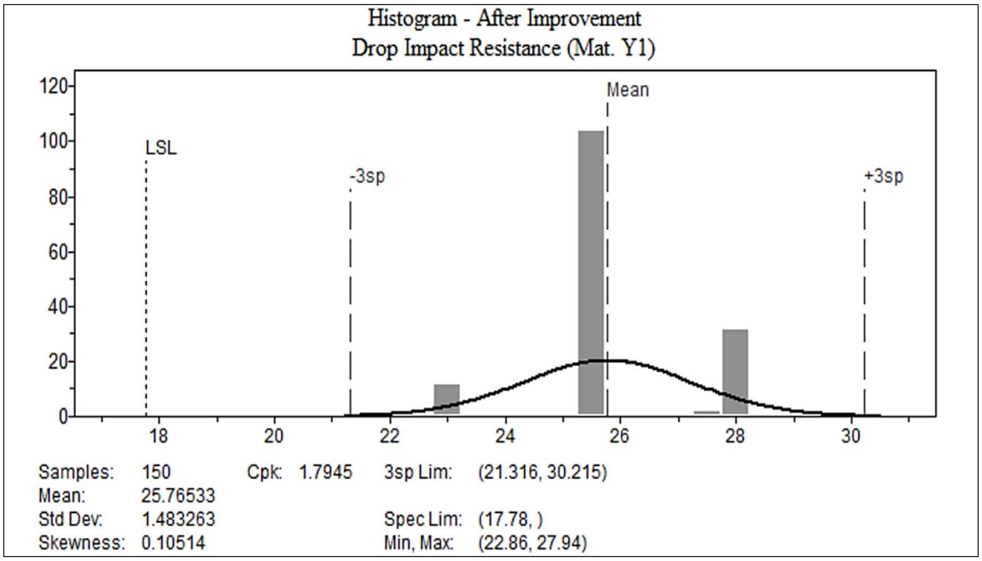


Figure 8 – Histogram of Drop Impact Resistance after Improvement

The histogram in Figure 8, given the information that the potential capability index of DIR after doing action on the three (3) factors that causing faulty in the potential index capability achievement, is positive with the *Cpk* index 1.79.

4 STANDARDIZATIONS

Looking at Figure 9 below we can learn that after improvement the average DIR was increased from 20.40 cm to 25.76 cm, and the potential *process capability index (Cpk)* increased from 0.48 to 1.79.

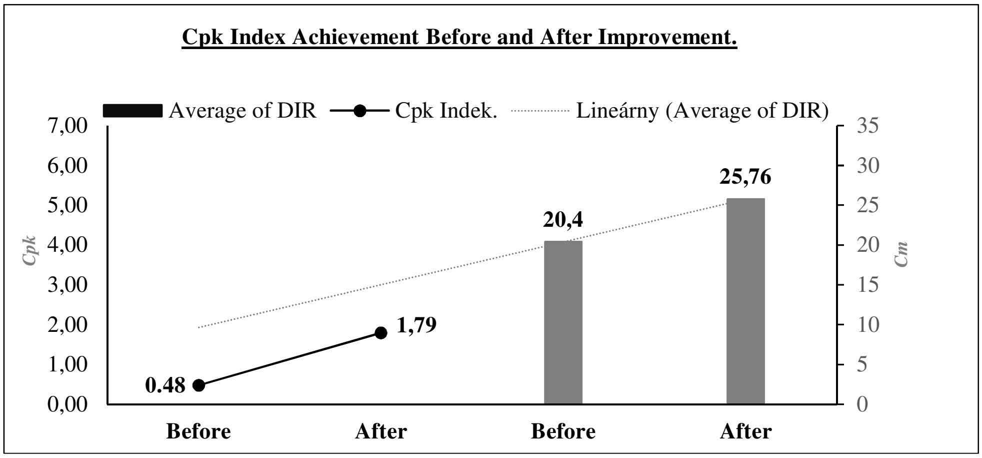


Figure 9 – The Achievement of Cpk and Average of DIR Test before Vs. after Improvement

The achievement as in Figure 9, then plotted into the distribution plot, as shown in Figure 10.

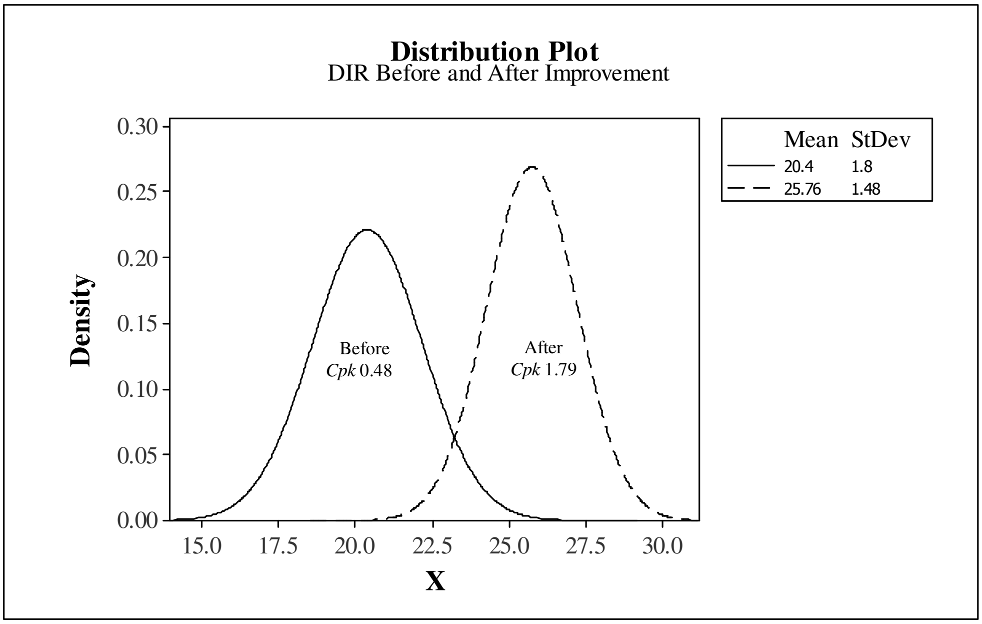


Figure 10 – Distribution Plot of DIR before and after Improvement

Based on Figure (7, 8, 9, and 10), the process stability and capability results for the DIR are ideal categorized, and it can be seen in the control and capable matrix in Figure 11.

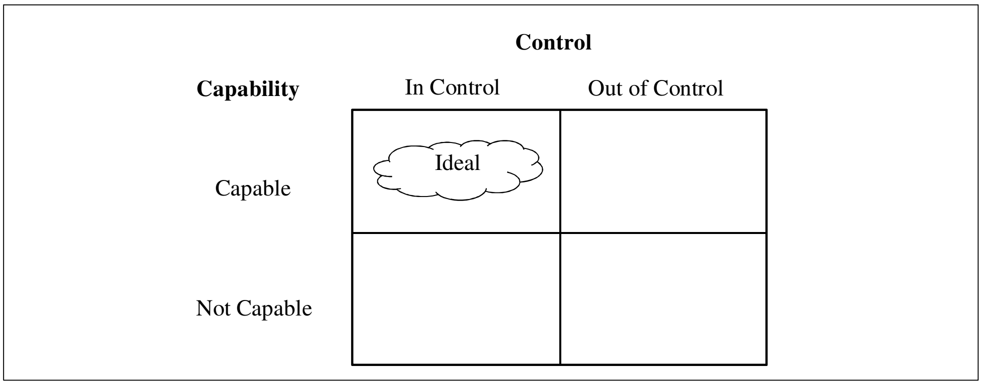
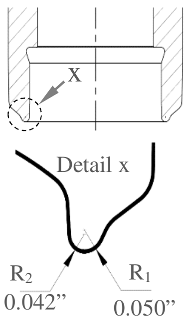
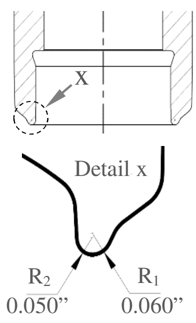


Figure 11 – Matrix in Control and Capable (IC &C) of the Process

After getting the improvement results, then determining the standardization to maintain the stability and the capability of the process, as shown in Table 14.

Table 14 – Data before and after Improvements as Standardization

No.	Dominant Factors	Before	After	Standardization
1	Air pressure was injected into the cans is fluctuated, so the DIR test results becoming unstable.	Unstable reading on the pressure gauge indicator.	Changing the pressure gauge indicator and put on the permanent mounting.	Pressure Gauge Indicator, put in calibration schedule to make well control.
2	Temperature oven dryer washer set point over then 420ºF.	Cans drying process was using one oven zone with setpoint temperature 430ºF with curing time 1 minute and 26 seconds.	Cans drying process is using two oven zones with setpoint zone 1: 385º F and zone 2: 395ºF, with curing time 2 minutes and 52 seconds.	Issue Oven Card, monthly bases, and verified by Engineering and Quality Assurance Manager.
3	*The tooling geometry* of the punch sleeve does not match for new aluminum thickness material (Y_1).	Punch Nose Radius R_1: 0.050 Inch R_2: 0.042 Inch 	Punch Nose Radius R_1: 0.060 Inch R_2: 0.050 Inch 	Revision Technical Drawing of Punch Sleeve. Documents: 0106384, Rev 1 (29-07-19).

5 CONCLUSION AND RECOMMENDATION

The study was implementing the SPC to analyze the data, PDCA to continuous improvement, CED to determine the root cause and *NGT* to determine the dominant cause factors, and then 5W1H method to manage the improvement. It's very useful and effective in creating and improves aluminum cans packaging product quality.

The fact is the average of DIR increased from 20.40 cm to 25.76 cm, the standard deviation was reduced from 1.80 to 1.48 and the potential *process capability index (Cpk)* increased from 0.48 to 1.79, it can be concluded that the process is stable and capable.

The significant impact for the company was the company to be able to use aluminum material Y_1 to produce aluminum cans packaging with high-quality standards.

To maintain the process stability and capability are always meet to the specification, it needs to be well controlled for the parameters i.e.: 1) Air pressure which is injected into the inside of the cans when doing the DIR test to make sure stables. 2) The washer-dryer oven machine the temperature setpoint needs to be controlled to do not exceed 420° F with two zones oven activation to avoid aluminum softening or annealing if any machine stops for a while. 3) To avoid the stretching during the doming process, which is caused by tooling geometry of the punch sleeve nose radius, it needed to do regular checks to maintain the clearance is match with the Y_1 materials.

At the end of this study, further discussion is needed to maintain what has been successfully achieved. The recommendations for future researchers to make it better is highly recommended to use the FMEA method because it has an RPN (Risk Potential Number) index, so it will be more accurate to make justifications establish the improvements.

ACKNOWLEDGEMENTS

This article was created with financial support from Mercu Buana University, Jakarta, Indonesia, to motivate the student and lecturer to have an innovative research thinking base.

REFERENCES

Ani, M.N.C., Ishak, A.A. and Shahrul, K., 2016. Solving Quality Issues in Automotive Component Manufacturing Environment by utilizing Six Sigma DMAIC Approach and Quality tools. In: IEOM (Industrial Engineering and Operations Management), *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management.* Kuala Lumpur, Malaysia, 08-10 March 2016. IEOM Society International. pp.1986-1997.

Bereman, M.S., Johnson, R., Bollinger, J., Boss, Y., Shulman, N., MacLean, B., Hoofnagle, A.N. and MacCoss, M.J., 2014. Implementation of Statistical Process Control for Proteomic Experiments Via LC-MS/MS. *Journal of The American Society for Mass Spectrometry,* [e-journal] 25(4), pp581-587. DOI: 10.1007/s13361-013-0824-5.

Chakraborty, A., 2016. Importance of the PDCA cycle for SMEs. *International Journal of Mechanical Engineering,* [e-journal] 3(5), pp.30-34. DOI: 10.14445/23488360/IJME-V3I5P105.

Darmawan, H., Hasibuan, S. and Hardi Purba, H., 2018. Application of Kaizen Concept with 8 Steps PDCA to Reduce in Line Defect at Pasting Process: A Case Study in Automotive Battery. *International Journal of Advances in Scientific Research and Engineering*, [e-journal] 4(8), pp.97-107. DOI: 10.31695/IJASRE.2018.32800.

Devani, V. and Wahyuni, F., 2017. Pengendalian Kualitas Kertas Dengan Menggunakan Statistical Process Control di Paper Machine 3. *Jurnal Ilmiah Teknik Industri*, [e-journal] 15(2), pp.87-93. DOI: 10.23917/jiti.v15i2.1504.

Dhounchak, D. and Biban, L.K., 2017. Total Quality Management and Its Applications. *International Journal of Scientific Research in Mechanical and Materials Engineering,* [e-journal] 1(1), pp.15-17.

Fazeli, A.R. and Sharifi, E., 2011. Statistical Control and Investigation of Capability of Process and Machine in Wire Cut Edm Process of Gas Turbine Blade Airfoil Tip. *Engineering,* [e-journal] 2011(3), pp.260-265. DOI: 10.4236/eng.2011.33030.

Godina, R., Matias, J.C.O. and Azevedo, S.G., 2016. Quality Improvement With Statistical Process Control in the Automotive Industry. *International Journal of Industrial Engineering and Management,* 7(1), pp.1-8.

Mohamed, N.A., 2016. Evaluation of the Functional Performance for Carbonated Beverage Packaging: A Review for Future Trends. *Evaluation*, *39*. pp.53-61.

Magar, V.M. and Shinde, D.V.B., 2014. Application of 7 Quality Control (7 QC) Tools for Continuous Improvement of Manufacturing Processes. *International Journal of Engineering Research and General Science*, 2(4), pp-364-371.

Mangesha, Y., Singh, A.P. and Amedie, W.Y., 2013. Quality improvement using statistical process control tools in glass bottles manufacturing company. *International Journal for Quality research,* 7(1), pp.107-126.

Nabiilah, A.R., Hamedon, Z. and Faiz, M.T., 2018. Improving Quality Of Light Commercial Vehicle. *Using PDCA Approach. Journal of Advanced Manufacturing Technology* (JAMT), 12(1-1), 10p.

Nugroho, R.E., Marwanto, A. and Hasibuan, S., 2017. Reduce Product Defect in Stainless Steel Production Using Yield Management Method and PDCA. *International Journal of New Technology and Research* (IJNTR), 3(11), pp.39-46.

Ramirez, B. and Runger, G., 2006. Quantitative Techniques to Evaluate Process Stability. *Quality Engineering*, [e-journal] 18(1), pp.53-68. DOI: 10.1080/08982110500403581.

Rana, M., Zhang, X. and Akher, S.A., 2018. Determination of Factors and Quality Control of Car Painting Based on FMEA and SPC.V2. *Modern Mechanical Engineering*, [e-journal] 8(2), pp.158-177. DOI: 10.4236/mme.2018.82011.

Realyvásquez-Vargas, A., Arredondo-Soto, K., Carrillo-Gutiérrez, T. and Ravelo, G., 2018. Applying the Plan-Do-Check-Act (PDCA) Cycle to Reduce the Defects in the Manufacturing Industry. A Case Study. *Applied Sciences,* [e-journal] 8(11), 17p. DOI: 10.3390/app8112181.

Sagbas, A., 2009. Improving The Process Capability Of A Turning Operation By The Application Of Statistical Techniques. *Materiali in Tehnologije*, 43(1), pp.55-59.

Saputra, T., Hernadewita, H., Prawira Saputra, A.Y., Kusumah, L. and ST, H., 2019. Quality Improvement of Molding Machine through Statistical Process Control in Plastic Industry. *Journal of Applied Research on Industrial Engineering*, [e-journal] 6(2), pp.87-96. DOI: 10.22105/jarie.2019.163584.1068.

Sharma, G. and Rao, P.S., 2013. Process capability improvement of an engine connecting rod machining process. Journal of Industrial Engineering International, [e-journal] 9, 37. DOI: 10.1186/2251-712X-9-37.

Sharma, G., Rao, P.S. and Babu, B.S., 2018. Process capability improvement through DMAIC for aluminum alloy wheel machining. *Journal of Industrial Engineering International*, 14, pp.213-226. DOI: 10.1007/s40092-017-0220-z

Sokovi, M., 2009. Basic Quality Tools in the Continuous Improvement Process. *Strojniski Vestnik*, 55(5), pp.333-341.

Solihudin, M. and Kusumah, L.H., 2017. Analisis Pengendalian Kualitas Proses Produksi Dengan Metode Statistical Process Control (SPC) Di PT. Surya Toto Indonesia, Tbk. In: ITN Malang, *Seminar Nasional Inovasi Dan Aplikasi Teknologi Di Industri 2017*. Malang, 4 February 2017. C31.1-8.

Supriyadi, E., 2018. Analisis Pengendalian Kualitas Produk Dengan Statistical Proses Control (SPC) Di PT. Surya Toto Indonesia, Tbk. *Jurnal Ilmiah Teknik dan Manajemen Industri*, [e-journal] 1(1), pp.63-73. DOI: 10.32493/jitmi.v1i1.y2018.p%25p.

Tuna, S., 2018. Keeping Track of Garment Production Process and Process Improvement using Quality Control Techniques. *Periodicals of Engineering and Natural Sciences*, [e-journal] 6(1), pp.11-26. DOI: 10.21533/pen.v6i1.162.

Trimarjoko, A., Saroso, D.S., Purba, H.H., Hasibuan, S., Jaqin, C. and Aisyah, S., 2019. Integration of nominal group technique, Shainin system and DMAIC methods to reduce defective products: A case study of tire manufacturing industry in Indonesia. *Management Science Letters*, [e-journal] 9, pp.3421-2432. DOI: 10.5267/j.msl.2019.7.013.

ABOUT AUTHORS

Sunadi Sunadi – Mercu Buana University, Jakarta, Indonesia, Industrial Engineering and Management Program, Postgraduate student, e-mail: sunadi210770@gmail.com, Author's ORCID: 0000-0002-2940-6480.

Humiras Hardi Purba – Mercu Buana University, Jakarta, Indonesia, Industrial Engineering and Management Program, Lecturer, e-mail: hardipurba@yahoo.com, Author's ORCID: 0000-0002-8166-6845.

Sawarni Hasibuan – Mercu Buana University, Jakarta, Indonesia, Industrial Engineering and Management Program, Lecturer, e-mail: sawarni02@mercubuana.ac.id, Author's ORCID: 0000-0003-4477-4190.

AUTHOR CONTRIBUTIONS

S.S. – conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing - original draft preparation; H.H.P. – writing - review and editing, visualization, supervision; S.H. – project administration, funding acquisition.

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 1

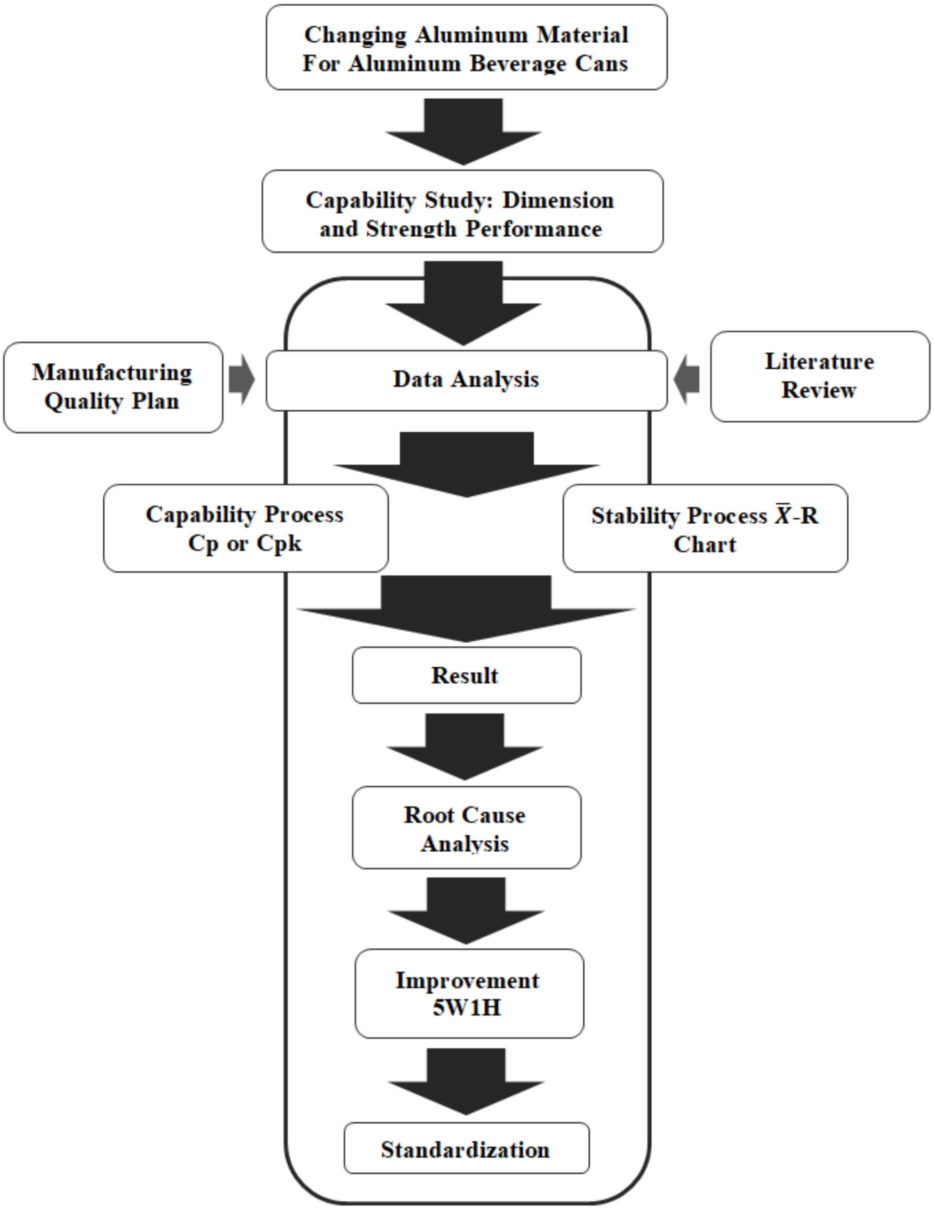


Figure A1 – Research Framework

Modelling of an Additive 3D-Printing Process Based on Design of Experiments Methodology

DOI: 10.12776/QIP.V24I1.1435

José Alberto Eguren, Aritz Esnaola, Gorka Unzueta

Received: 2020-02-29 Accepted: 2020-03-29 Published: 2020-03-31

ABSTRACT

Purpose: The implementation of additive manufacturing (AM) or 3D-printer manufacturing for technical prototyping, preproduction series and short production series can bring benefits in terms of reducing cost and time to market in product development. These technologies are beginning to be applied in different industrial sectors and have a great possibility of development. As these technologies are still in development, there is a need to define the capacity of the 3D machines to establish minimum standards for producing high-quality parts. In order to understand the behaviour of the different parameters of the 3D-manufacturing process and define the numerical prediction models to produce high-quality parts, the University of Mondragón has carried out the study presented in this article on a new 3D printer recently purchased for the research laboratories.

Methodology/Approach: The proposed methodology is based on a design of experiments (DOE) approach, which serves as a guide for engineers when it comes to executing any experimental study.

Findings: The study has improved understanding in two areas of action: the behaviour of 3D technologies and the application of improvement methods based on the DOE methodology. We identified key factors for optimising the new technology, including an impression in 3D.

Originality/Value of paper: This study uses a methodological approach to demonstrate how the 3D printing technology can be enriched with statistical testing techniques (DOE). It defines numerical prediction models to obtain high-quality parts with a new AM technology, using a planning process with a minimum amount of experimentation.

Category: Case study

Keywords: quality improvement; DOE; 3D printer; additive manufacturing

1 INTRODUCTION

Additive manufacturing (AM) is the formalised term used for rapid prototyping, which describes a process used to create systems or parts rapidly before the final presentation of the product. The term ‘3D printing’, describes the processes of converting a 3D computer-aided design (CAD) model into a stereo lithography (STL) triangular lattice surface model, and then creating the solid parts through layer-upon-layer production. In this way, AM changes the way industrial companies operate. This technology is in the early stages of development, so manufacturers are prudent.

This process has mainly been used to create prototypes quickly to verify the details before beginning the formal production process (Gibson, Rosen and Stucker, 2015). The possibility of obtaining parts with better characteristics is currently being studied as an alternative production method that can compete with traditional parts and processes (Narang and Chhabra, 2017; Rayegani and Onwubolu, 2016).

The implementation of AM for technical prototypes, preproduction series and short series of production can offer benefits in terms of cost reduction and reduction of time to market in product development (Khajavi, Partanen and Holmström, 2014; Li, Kucukkoc and Zhang, 2017). These technologies have applied in different industrial sectors and have a strong potential for development. Additive manufacturing is increasingly becoming a true production process, used to create end-use products. That is why speed and quality have also become increasingly important (Moreau, 2018). One of the industrial sectors where AM has experienced great development is the equipment goods sector, which has adopted AM as a method of prototyping and production. In addition, many of the benefits of AM are related to problems of production: in the equipment goods sector, for example, in the equipment goods sector, for example, time reduction and more pressing issues than they are in other industrial sectors. For this reason, AM is seen as a key manufacturing method for the equipment goods sector (Moreau, 2018).

To be competitive in the global markets, manufacturers must have complex and flawless manufacturing processes and reliable supply chains to deliver high-quality final products. Manufactured components must demonstrate indisputable performance before use in highly regulated industries, where lives can be affected. Additive manufacturing products will be increasingly competitive with improvements in processing, performance, scalability, affordability and qualification. High-precision computational models will improve the design and processing of AM products. To enable validation, models must be able to predict the exact properties of the product reliably based on the processing parameters (Office of Technology Transition, 2019).

There is currently not enough practice and knowledge available to develop serial manufacturing processes related to AD technologies efficiently. It is necessary to have a thorough knowledge of the technologies used and their influence on the final properties of the components. Therefore, methods are required to support the generation of a technological knowledge base and identify the cause–effect relationships of the AD machines process parameters with the outputs obtained to establish the minimum standards required to produce high-quality parts (Cruz et al., 2014; Rayegani and Onwubolu, 2016). For this reason, it is necessary to analyse and evaluate the capacity of the machines to establish minimum performance standards (Narang and Chhabra, 2017).

Robust modelling tools, high-performance computing and experimental observations can help verify existing models and identify new physical processes and their implications. For this, tools based on modelling of the DOE can help accelerate the development and modelling of the AD processes and allow efficient homologation of the manufactured parts. By improving these aspects of AM, the DOE allows distributed AM to increase the efficiency of the supply chain significantly (Wiemer et al., 2017).

This article presents the results of a study carried out on a new 3D printer recently acquired for the research laboratories of the University of Mondragón. The main objective of this article is to develop an understanding of the behaviour of the different parameters of fusion deposition modelling (FDM) technology framed within AD technologies. To this end, a methodological approach has been developed to demonstrate how it can be enriched with statistical testing techniques, such as DOE, and define numerical prediction models to obtain high-quality parts. The current study focused on the industrial sector of capital goods, specifically on manufacturing moulds for vacuum-assisted infusion processes. These moulds are applied in the manufacturing of skateboard and drone structures.

This article is structured as follows. In section 2, the application of the proposed methodology in the case of the AM is described. Subsequently, in section 3, a general overview of AM processes is provided. The DOE development for the case is discussed in section 4, and the conclusions and final perspectives are presented in section 5.

2 METHODOLOGY

State of the art DOE offers numerous established algorithms, which can be applied to various technological development tasks. However, in practice, there are often serious obstacles that must be overcome to use these algorithms. The availability of software tools for DOE is not the main problem since there are numerous software tools for the statistical DOE. In the case in question, an analysis was conducted with Minitab 18 software, which offers the possibility of applying the DOE algorithms in a simple way. However, only mathematicians or engineers with additional qualifications can use these algorithms properly. It is quite difficult for an engineer to select the best DOE algorithm for a task in question and parameterise the design. The main reason for this is that experimental tasks and the requirements for the necessary analysis results are quite complex, so many engineers avoid using them. This means that the potential offered by DOE methods focused on generating maximum knowledge with minimum effort is not fully utilised (Wiemer et al., 2017).

In addition, in an AM process, the parts produced must simultaneously meet different types of mechanics and dimensional requirements. To address this problem, the research community has used the DOE to optimise the individual manufacturing parameters of the machines. However, the selection of a combination of machine and process parameters to meet multiple requirements simultaneously has not been addressed. There is then a need to investigate a systematic experimental approach to meet multiple production requirements simultaneously and characterise manufacturing capabilities, as proposed in a similar manufacturing context (Ituarte et al., 2015). To this end, the methodology shown in Figure 11 is proposed to address the DOE in the present study (Unzueta et al., 2019). This serves as a guide for engineers when it comes to execute any experimental study based on the DOE. The proposed methodology steps are described in the following paragraphs.

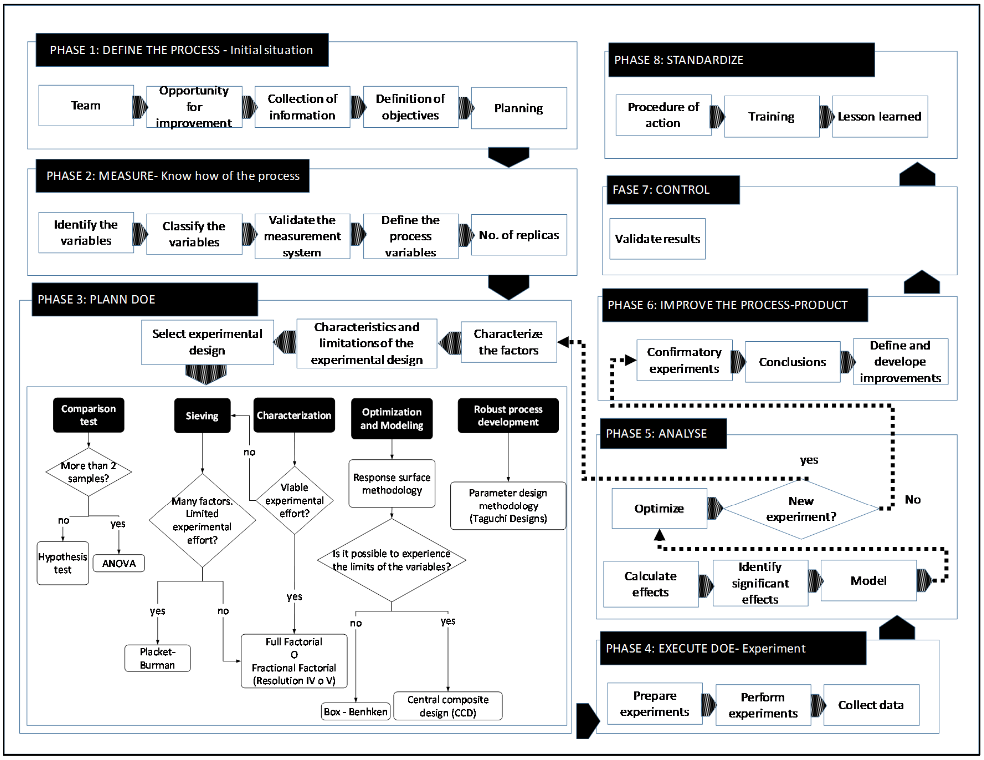


Figure 1 – Methodology for the Application of the DOE (Source: Unzueta et al. (2019))

Phase 1: Define

In this phase, the work team, the process and related information, and the objective of the experimentation are defined. The team must be composed of members familiar with the process for analysis who are able to identify the factors that can influence the response. Usually, the collection of information consists of identifying the parameters of the normal operation of the process.

Phase 2: Measure

In this phase, the process factors that influence the output are identified and classified to obtain the maximum information that allows for the minimum experimental effort. These are classified as controllable factors and non-controllable factors (noise). The controllable factors include those the experimenter can consciously modify regarding the level of functioning in each experiment. For the factors identified as non-controllable, a strategy must be defined to reduce their influence and attempt to keep them constant.

Phase 3: Plan

To select the appropriate experimental design, it is necessary to consider the characteristics and limitations of the process:

- The total number of experiments that can be executed considering the constraints of the process (experimental effort);
- The number of factors, controllable and non-controllable;
- The experimental range and levels of experimentation factors.

Depending on the characteristics of the process and the objective pursued, the appropriate experimental design is selected.

In the flow diagram of Phase 3 (Figure 1), different options are presented based on the objective pursued:

- To compare different situations, a comparison test can be carried out;
- To analyse the process when there is a limit to the number of experiments to be executed, a sieving design can be used to discard the less influential factors;
- To determine the influence of a certain number of factors with sufficient availability of resources, a characterisation based on factorial designs can be carried out;
- To optimise and to model the process with significant factors at more than two levels, a response surface methodology can be used;
- To develop robust processes, the experimental designs of Taguchi can be used.

Phase 4: Execute experimentation

In this phase, experiments are prepared and executed in the most rigorous and methodical way possible.

Phase 5: Analyse the results of the experimentation

The analysis of the results of the experimentation is based on the calculation of the effects of each factor and the factor's influence on the response of the process. The effect of a factor on the response is defined as the variation observed in the response by varying the level of the factor.

By applying the methodology, it is possible to determine the model of the process within the experimental zone used. When the calculations are completed, the coefficients of the polynomial model are defined (without quadratic terms), in the form shown in equation (1):

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 AB + \beta_5 AC + \beta_6 BC \tag{1}$$

Where, β_0 is the average of the result of the experiments. β_i is the coefficient of each factor (half of the calculated effect). The values *A*, *B*, and so forth are the values that each factor or interaction takes (+1, -1).

Phase 6: Improve via confirmation experiments

In this phase, once the optimisation is completed, confirmatory experiments are carried out to confirm the levels of each factor identified as adequate.

Phases 7-8: Control and standardise

In these phases, once the significant factors and the levels that improve the response are defined, it is necessary to standardise the process and determine the controls that ensure the maintenance of adequate levels.

3 ADDITIVE MANUFACTURING

Additive manufacturing is a new group of technologies that, although still evolving, are projected to exert a profound impact on manufacturing. They can give industry new design flexibility, and shorten time to market. All AM technologies involve several processes, but these processes are often similar. In general, AM technologies involve eight different stages, which include creating the CAD model, converting this design to the STL format, transferring this format to the AM machine, configuring the machine, building parts, removing the pieces produced in the machine, and, if necessary, post-processing and using applications for additional treatments, such as painting and priming (Kumbhar and Mulay, 2018; Wong and Hernandez, 2012).

The first task is to develop an idea and to visualise it. It is possible to visualise any type of product with a CAD model. Next, to avoid issues related to unreliable products not completely included, it is necessary to change the CAD model to an STL format, which creates the geometry of the surface of the object using triangles in three dimensions without any representation of colour, texture or other attributes of the model. After creating this file, it is necessary to send this document to the AM machine to create it immediately. After configuring the machine, the process will continue with the computer-controlled construction phase. In this phase, the AM machine begins to produce the object that is recognised by the machine. Following this step, the producer removes the object from the machine and cleans it for further processing. Most parts made with additives will require further processing. In this step, the object is prepared for the client's use by painting it, polishing it, sanding it, and so forth (Wong and Hernandez, 2012).

This technology, which was first introduced in 1987, is still considered new and continues to be developed with new methods and materials, according to the sector. Over time, AM has been adopted by new sectors, which means that new types of AM technologies will continue to be developed. This technology is already used in many sectors, including architecture, medicine, automotive, aerospace, transportation, art, energy, commercial products, defence, education and electronics (Gausemeier, Wall and Peter, 2013; Wong and Hernandez, 2012).

Additive manufacturing has been used in the medical sector almost since its inception. The first of the AM applications in the medical sector was the use of computerised tomography to create images of subjects from any angle. In addition, AM has been applied in different categories of medical applications, such as for surgical and diagnostic aids, prosthesis development, and manufacturing related to medicine and tissue engineering (Chepelev et al., 2017; Tofail et al., 2018).

The aerospace sector is another sector that has used AM since its initial introduction. The aerospace sector uses complex geometric shapes that are difficult to produce, requiring many steps to produce a piece; however, with the application of AM, many steps can be omitted. This is the biggest reason that AM is favoured in this sector, but there are many other reasons to apply this technology in this sector as well: AM can be used to produce light parts, complex shapes and digital parts, and can reduce the cost of production because it does not produce the same parts required by conventional manufacturing processes (Lipson et al., 2012). In the automotive sector, AM was also used to produce parts, but most manufacturers decided not to pursue this technology for the mass production of automobiles due to the high cost of production (Dwivedi, Srivastava and Srivastava, 2015).

The materials used in the first applications of AM were plastics, but after further developments, metals, ceramics and composites of these materials are now also being used for this technology. Following such developments, AM has continued to evolve rapidly, and today is applied in many sectors. Metals are being used in the form of completely molten particles. Specifically, SnS, Ti6Al4V, stainless steel 316L, 17-4 PH, tool steels, nickel alloys, cobalt alloys and titanium alloys are examples of metal materials used in AM technology. Polymers also are being used in AM, which have been used since the introduction of this technology. Plastics, acrylic plastics, wax, ABS, photo-curable resins, polyamide, polystyrene, ULTEM and PC are examples of polymer materials used in AM. Ceramics are also widely used in AM, but it is difficult to use them to produce complex parts because they have a high degree of hardness and brittleness. Specifically, zirconia, silica, alumina, PZT, bioceramic, sand, graphite and industrial ceramics, such as Si3N4 and Al2O3, are used. Composites are engineered or naturally occurring materials made from two or more constituents, and they are widely used in AM technologies. Some composite materials used include Fe-Cu, TiC-Ni, steel-Cu, polymer matrix and fibre-reinforced composites (Guo and Leu, 2013).

There are various ways to classify the AM technologies, such as by baseline technologies or by their raw material input; however, using one type of classification seems to provide a better understanding of the technology. In 2010, the American Society for Testing and Materials (ASTM) group "ASTM F42-AM" (Harris, 2019) formulated a set of standards that classify the range of AM processes into seven categories: vat photopolymerisation, material jetting, binder jetting, material extrusion, powder bed fusion, sheet lamination and directed energy deposition (Kumbhar and Mulay, 2018).

Additive manufacturing faces many challenges and barriers; they must be overcome in order to integrate this technology as amongst the current manufacturing processes. Some challenges are related to the development of process control systems in order to incorporate feedback control systems, and metrics to improve accuracy, reliability and quality. There is also a need to improve the manufacturing price in order to be able to machine parts on micron scales or produce quality pieces in terms of surface finishes, which can achieve the desired tribological and aesthetic properties.

Processing speed is another challenge to overcome in order to develop high-performance additive processing methods to compete with conventional techniques. Additionally, the capacity to produce large volumes, both in size and in the number of pieces produced, must be addressed. Finally, the development of processes capable of producing products with new metallic materials and polymers formulated for AM, which provide specific application properties, such as flexibility, conductivity and transparency, stands out (Office of Technology Transition, 2019).

4 DESIGN OF EXPERIMENTS: DEVELOPMENT FOR THE CASE

The results described in the following paragraphs are the consequence of the application of the DOE methodology on the case study, following the steps described in section 3.

Phase 1: Definition of the case study

Fused deposition modelling (FDM) is a leading AM technology that is grouped into the category of extrusion-based systems used to manufacture solid prototypes with various materials directly from CAD data. Extrusion is a method used to create objects of a fixed cross-sectional profile. As the name implies, extrusion-based systems create parts by successively depositing layers via the controlled flow of a semi-liquid raw material through a nozzle in the deposition head assembly. The resulting material will maintain a constant cross-sectional diameter. Next, the AM machine starts and stops the flow of the material while scanning to complete the layer and then adds additional layers (Gibson, Rosen and Stucker, 2015).

The quality and strength of FDM construction parts depend essentially on the process parameters. To understand the performance and behaviour of FDM construction parts, the influence of process parameters on the quality of the result of construction parts must be studied (Venkatasubbareddy, Siddikali and Saleem, 2016). For this case study, the FDM process was used to create the samples. This process was performed in the laboratories of Mondragón University, as shown in Figure 2.

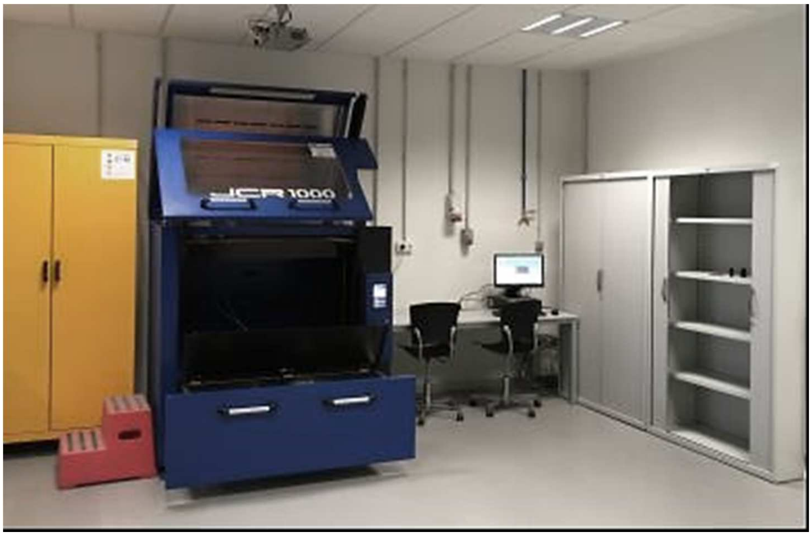


Figure 2 – Fused Deposition Modelling Equipment Acquired by the Laboratories of Mondragón University

The part created for the case study had a standard design analysed by the tensile test. To verify the mechanical properties of the composite material, the 3D model of the tensile test specimen was created according to EN ISO 527-2 standard (ISO, 2012). All the parts were made from polylactic acid (PLA). This material is a thermoplastic polymer. It is a standard polymer used in 3D printing with FDM technology. This material has some advantages: it is biodegradable because it is derived from renewable feedstock, such as starch, and its contraction during the

ISSN 1335-1745 (print) ISSN 1338-984X (online)

cooling phase is weak. It has good geometrical stability during its fabrication, and it uses low temperature to transform (merger point around 180°C). Generally, PLA is used for the creation of objects for the food processing industry or decoration without mechanical stress. In Figure 3, the dimensions of the sample tested are shown.

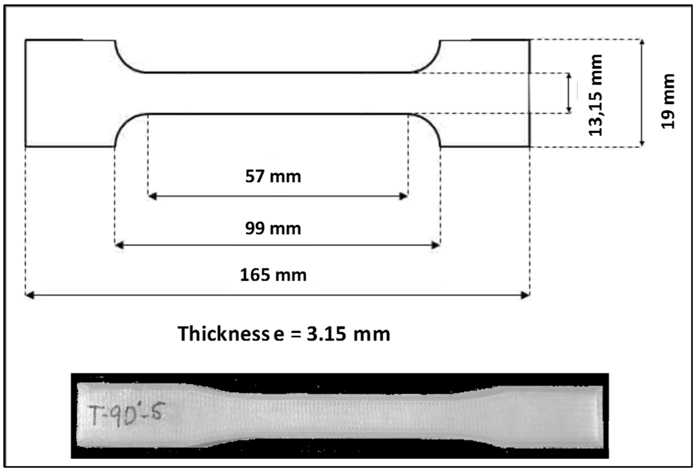


Figure 3 – Dimensions of the Sample Tested

To evaluate the mechanical properties of the created specimens, tensile tests were carried out in the laboratory of Mondragón University according to EN ISO 527. The machine used for the tensile test was the Instron by Zwick/Roell, which is shown in Figure 4.

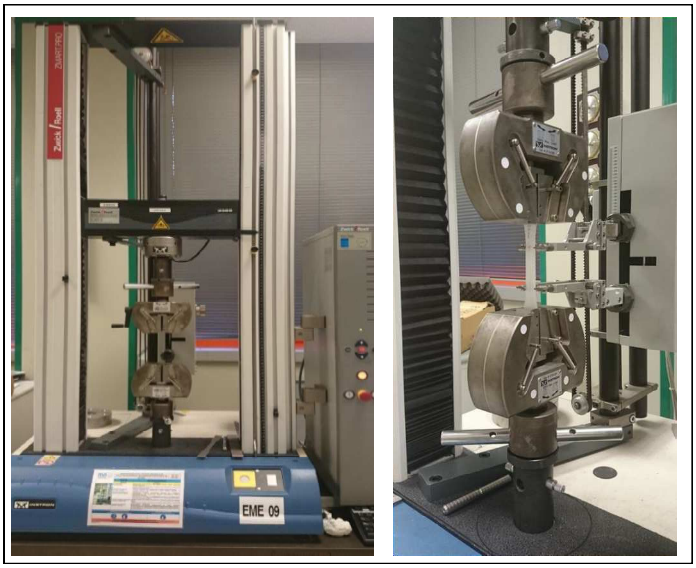


Figure 4 – Machine Used for the Tensile Test

Phase 2: Measurement of the case study

The quality and strength of FDM construction parts depend essentially on the process parameters. To understand the performance and behaviour of FDM construction parts, the influence of process parameters on the quality of the result of construction parts must be studied. Numerous studies have been carried out in this field, where the most important parameter levels of the FDM have been analysed for different quality characteristics of the construction pieces, including the thickness of the layer, air space, width of the plot, plot orientation, temperature and deposition rate (Sood, Ohdar and Mahapatra, 2010; Anitha, Arunachalam and Radhakrishnan, 2001; Prasad, Krishna and Venkatasubbareddy, 2014; Venkatasubbareddy, Siddikali and Saleem, 2016).

In the present study, the aforementioned information has been taken as a basis and brainstorming has been carried out to identify new factors. Strategies to be followed for each factor have been assigned. Table 1 shows the most important factors that affect the process and its classifications.

Table 1 – The Most Important Factors that Affect the Process and Their Classifications

Nº	Factor	Factor type	Classification	Strategy	Expected effect	Factor range
1	*Extruder temperature*	*Continuous*	*Controllable*	*Control*	*Positive*	*180 - 200 ºC*
2	*Nozzle movement speed*	*Continuous*	*Controllable*	*Control*	*Negative*	*40 mm/sec - 80 mm/sec*
3	*Thickness of Layer*	*Continuous*	*Controllable*	*Control*	*Positive*	*0.1 mm - 0.3 mm*
4	*Extrusion Width*	*Continuous*	*Controllable*	*Control*	*Positive*	*0.55 - 0.75*
5	*Test Tube Position*	*Discrete*	*Controllable*	*Control*	*Positive*	*Horizontal - Vertical*
6	*Internal fill angle*	*Discrete*	*Controllable*	*Control*		*0º-90º*
7	Nozzle type	*Discrete*	*Controllable*	*Use the nozzle, recommended by the manufacturer*	Null influence	0.6
8	Material	*Discrete*	*Controllable*	*Use the same material*	Null influence	Polylactic acid PLA
9	Overlap: last layer – perimeter	*Continuous*	Controllable	Use the same value	Null influence	0,15
10	First layer (speed, ...)	*Continuous*	Controllable	Use the same value	Null influence	Established by the manufacturing CNC program
11	Position on the table (quadrant)	*Discrete*	*Controllable*	Use the same position	Null influence	
12	Cooling	*Continuous*	Noise	Fans running, to cool the environment inside the printer		
13	Ambient temperature	*Discrete*	Noise	Randomize		
14	Ambient humidity	*Discrete*	Noise	Randomize		
15	Humidity, raw material	*Discrete*	Noise	Randomize		

The definitions of the controllable factors selected in this study are as follows:

- Temperature: Heat degree present to manufacture a product using 3D machines. Temperatures that are considered suitable by testers are 180º and 200º.
- Speed: Indicates how fast the filament is pulled back from the nozzle. The lowest level of speed for manufacturing is 40 mm/sec, and the highest level is 80 mm/sec.
- Thickness of layer: The nominal layer thickness for most machines is around 0.1 mm; however, it should be noted that this is only a general principle. The reasoning is that thicker layer parts are quicker to build but are less precise. In trials performed by testers, the lower level of thickness was 0.1 mm and the higher level was 0.3 mm.
- Extrusion width: A process used to create objects of a fixed cross-sectional profile. A material is pushed through a die of the desired cross-section. For the current study's case experiments, the lower and higher widths were respectively 0.55 and 0.75.
- Test tube position: The part orientation on the machine build platform in which geometries are manufactured horizontally or vertically.
- Internal fill angle: The process by which materials are used to fill created pieces (also known as infill). For the current study's case experiments, the special angle was chosen to be 0º-90º.

Table 2 shows a summary of the selected controllable factors.

Table 2 – Summary of Controllable Factors Selected

Cod	Variable	Experimental level	
		Lower Level	**Higher Level**
A	Temperature	*Continuous*	*Controllable*
B	Speed (Speed of Movement of the Nozzle)	*Continuous*	*Controllable*
C	Thickness of Layer	*Discrete*	*Controllable*
D	Extrusion Width	*Discrete*	*Controllable*
E	Test Tube Position	*Discrete*	*Controllable*
F	Infill (solid interior)-Internal fill angle	*Discrete*	*Controllable*

To conclude this phase, the number of replicas necessary to calculate the experimental error and analyse the significance of the effects and interactions was defined. To do this, a hypothesis test was carried out, considering the deviation of the results (σ), the maximum expected effect, the probability of a type I error (α) and the sample size (or the number of replicas). In the case of this study, the hypothesis test was performed defining two replicas (common in industrial processes), an expected effect of 20%, and $\alpha = 5\%$, obtaining a power of 0.96, which was adequate. As shown in Figure 5, two replicates are sufficient to obtain a power greater than 80% to observe a change in the response greater than 15% (stress at the moment of breakage [MPa]).

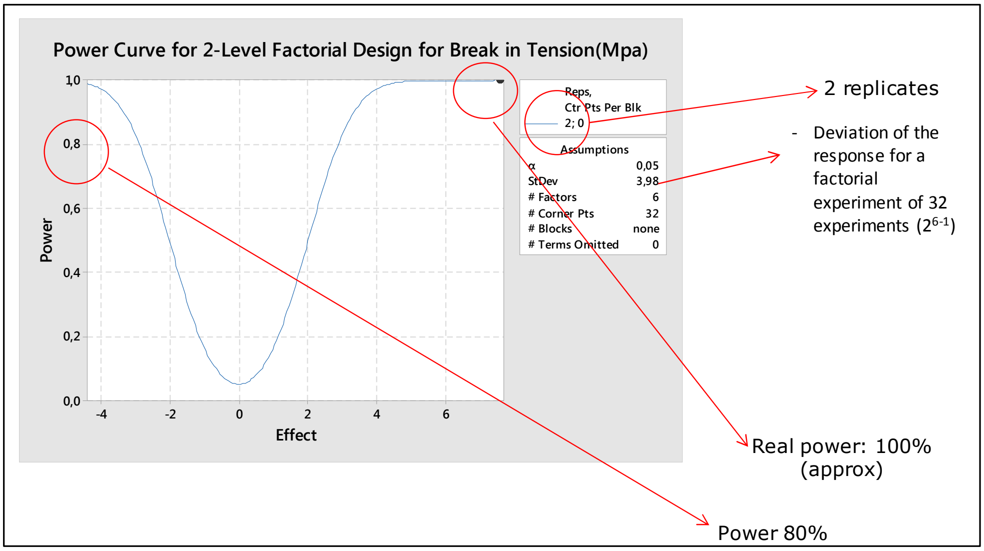


Figure 5 – Power Curve to Define the Numbers of Replicas

Phases 3-4: Planning and execution of the case study experiment

Following the indications of the methodology described in Phase 3, the case in question was developed within a context of characterisation, so the experimental strategy used corresponded with the factorial experimental design. Figure 6 shows different examples of the experimentation carried out.

Figure 6 – Examples of the Experimentation

Six controllable factors and two levels for each factor were identified, selecting a fractional factorial design (2^{6-1}) of resolution IV and two replicates for a total of 64 experiments. Three answers to be analysed were selected: the Young modulus (GPa), break in tension (MPa) and breakage deformation. The experimental design and the results of the experimentation are shown in Figure 7.

RunOrder	Temperature	Speed	Thickness of Layer	Extrusion Width	Test Tube Position	Internal Fill Angle	Young(GPa)	Break in Tension(MPa)	Breakage Deformation
1	180	40	0,1	0,55	Horizontal	0	2,70	24,10	0,01
2	200	40	0,1	0,55	Horizontal	90	3,13	30,71	0,01
3	180	80	0,1	0,55	Horizontal	90	2,53	27,42	0,01
4	200	80	0,1	0,55	Horizontal	0	3,07	30,64	0,01
5	180	40	0,3	0,55	Horizontal	90	3,34	37,85	0,01
6	200	40	0,3	0,55	Horizontal	0	3,34	34,10	0,01
7	180	80	0,3	0,55	Horizontal	0	2,47	25,06	0,01
8	200	80	0,3	0,55	Horizontal	90	2,82	32,25	0,01
9	180	40	0,1	0,75	Horizontal	90	3,28	42,33	0,01
10	200	40	0,1	0,75	Horizontal	0	3,17	42,70	0,02
11	180	80	0,1	0,75	Horizontal	0	2,90	45,98	0,02
12	200	80	0,1	0,75	Horizontal	90	3,07	53,49	0,03
13	180	40	0,3	0,75	Horizontal	0	3,31	42,74	0,01
14	200	40	0,3	0,75	Horizontal	90	3,08	42,57	0,02
15	180	80	0,3	0,75	Horizontal	90	3,40	55,63	0,03
16	200	80	0,3	0,75	Horizontal	0	3,60	48,41	0,02
17	180	40	0,1	0,55	Vertical	90	2,29	32,06	0,02
18	200	40	0,1	0,55	Vertical	0	3,39	39,56	0,02
19	180	80	0,1	0,55	Vertical	0	2,49	31,36	0,01
20	200	80	0,1	0,55	Vertical	90	3,23	43,15	0,02
21	180	40	0,3	0,55	Vertical	0	2,88	37,01	0,02
22	200	40	0,3	0,55	Vertical	90	2,95	38,03	0,02
23	180	80	0,3	0,55	Vertical	90	2,38	34,89	0,02
24	200	80	0,3	0,55	Vertical	0	2,84	35,53	0,02
25	180	40	0,1	0,75	Vertical	0	3,14	45,46	0,02
26	200	40	0,1	0,75	Vertical	90	3,65	55,94	0,05
27	180	80	0,1	0,75	Vertical	90	2,88	40,19	0,02
28	200	80	0,1	0,75	Vertical	0	2,89	37,14	0,02
29	180	40	0,3	0,75	Vertical	90	3,06	43,49	0,02
30	200	40	0,3	0,75	Vertical	0	3,27	53,64	0,02
31	180	80	0,3	0,75	Vertical	0	3,38	42,96	0,02
32	200	80	0,3	0,75	Vertical	90	3,02	42,54	0,02
33	180	40	0,1	0,55	Horizontal	0	2,64	18,69	0,01
34	200	40	0,1	0,55	Horizontal	90	3,00	18,77	0,01
35	180	80	0,1	0,55	Horizontal	90	3,24	18,17	0,01
36	200	80	0,1	0,55	Horizontal	0	2,94	20,65	0,01
37	180	40	0,3	0,55	Horizontal	90	2,43	17,58	0,01
38	200	40	0,3	0,55	Horizontal	0	3,04	21,80	0,01
39	180	80	0,3	0,55	Horizontal	0	3,27	20,77	0,01
40	200	80	0,3	0,55	Horizontal	90	3,20	23,84	0,01
41	180	40	0,1	0,75	Horizontal	90	3,52	50,57	0,02
42	200	40	0,1	0,75	Horizontal	0	3,12	33,42	0,01
43	180	80	0,1	0,75	Horizontal	0	3,14	38,00	0,01
44	200	80	0,1	0,75	Horizontal	90	3,14	45,55	0,02
45	180	40	0,3	0,75	Horizontal	0	3,56	48,15	0,02
46	200	40	0,3	0,75	Horizontal	90	3,62	55,75	0,02
47	180	80	0,3	0,75	Horizontal	90	3,64	56,47	0,02
48	200	80	0,3	0,75	Horizontal	0	3,44	55,49	0,02
49	180	40	0,1	0,55	Vertical	90	2,12	20,73	0,01
50	200	40	0,1	0,55	Vertical	0	3,83	20,31	0,01
51	180	80	0,1	0,55	Vertical	0	3,53	30,76	0,01
52	200	80	0,1	0,55	Vertical	90	1,86	12,04	0,01
53	180	40	0,3	0,55	Vertical	0	2,23	27,14	0,01
54	200	40	0,3	0,55	Vertical	90	1,39	9,60	0,01
55	180	80	0,3	0,55	Vertical	90	1,92	18,90	0,01
56	200	80	0,3	0,55	Vertical	0	2,84	27,87	0,01
57	180	40	0,1	0,75	Vertical	0	2,59	28,99	0,01
58	200	40	0,1	0,75	Vertical	90	2,40	20,93	0,01
59	180	80	0,1	0,75	Vertical	90	1,86	16,94	0,01
60	200	80	0,1	0,75	Vertical	0	1,68	14,05	0,01
61	180	40	0,3	0,75	Vertical	90	2,54	26,24	0,01
62	200	40	0,3	0,75	Vertical	0	2,57	34,97	0,04
63	180	80	0,3	0,75	Vertical	0	2,92	42,06	0,02
64	200	80	0,3	0,75	Vertical	90	2,70	36,81	0,02

Figure 7 – Experimental Design Matrix (2^{6-1}, 2 replicas)

Phase 5: Analysis of the results of the case study experimentation

When the experiments were analysed, the data were fitted to a model and estimated. The effects of the main factors and interaction terms were estimated. The analysis involved interpreting the influence that each variable had on the result.

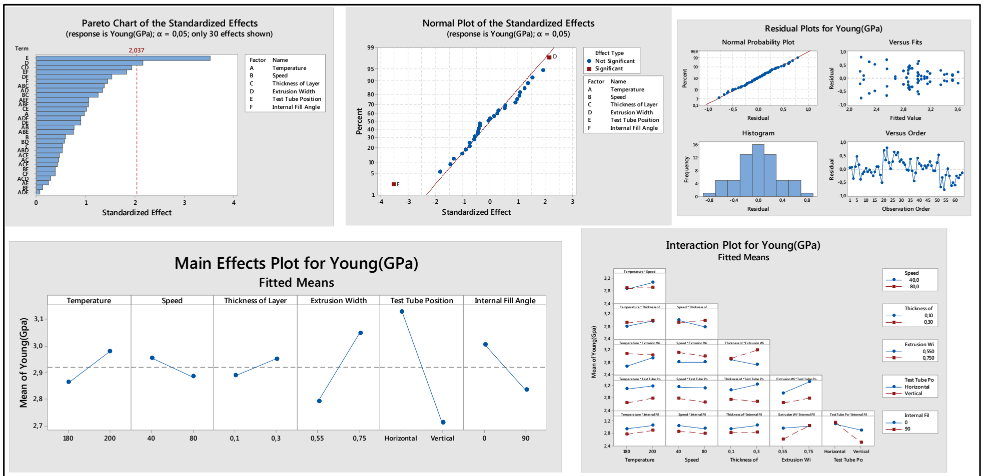
Experimentation can be difficult if too many variables are changed at the same time. There are many ways to comment on results that are obtained through data analysis. Pareto charts determine the magnitude and importance of the effects. In the chart, bars that cross the reference line are statistically significant. The Pareto chart displays the absolute value of the effects. It can determine which effects are significant, but it cannot determine which effects increase or decrease the response. This type of chart helped determines that 20% of the variables were the most influential for 80% of the results. This information is useful because it helps focus on the variables that have a significant effect.

The normal probability plot of the standardised effects was used to examine the magnitude and direction of the effects on one plot. The normal probability plot of effects shows the standardised effects relative to a distribution fit line for the case when all the effects are 0. The standardised effects are t-statistics that test the null hypothesis that the effect is 0. Positive effects increase the response when the settings change from at low value of the factor at the high value. Negative effects decrease the response when the settings change from at low value to at high value of the factor. Effects further from 0 on the x-axis have greater magnitude and are more statistically significant. In the following paragraphs, the results for each analysed response are discussed, for which the Minitab 18 software was used as support.

First answer: The Young modulus (GPa)

Figure 8 shows a summary of the results for the first answer: the Young modulus (GPa). It can be observed that the normal plot graphics are the variable test tube position (E), located at the left side of the graphics, so E has a positive effect on the Young modulus. The extrusion width (D) is fixed at the right side of the graph, which means that D has a negative effect on the Young modulus. For the Pareto chart, after the red line, variables D and E appeared. Thus, E is in the first place and has a greater effect on that response. The main effect plot graph has three non-horizontal lines through the x-axis, which are important for the response and include D, E and F, respectively. On the interaction plot graphs, the colour and shape of the points differ between statistically significant and statistically insignificant effects. On this plot, the main effects for factors D and E are statistically significant at the 0.05 level.

Additive manufacturing is a new group of technologies that, although still evolving, are projected to exert a profound impact on manufacturing. They can give industry new design flexibility, and shorten time to market. All AM technologies involve several processes, but these processes are often similar. In general, AM technologies involve eight different stages, which include creating the CAD model, converting this design to the STL format, transferring this format to the AM machine, configuring the machine, building parts, removing the pieces produced in the machine, and, if necessary, post-processing and using applications for additional treatments, such as painting and priming (Kumbhar and Mulay, 2018; Wong and Hernandez, 2012).



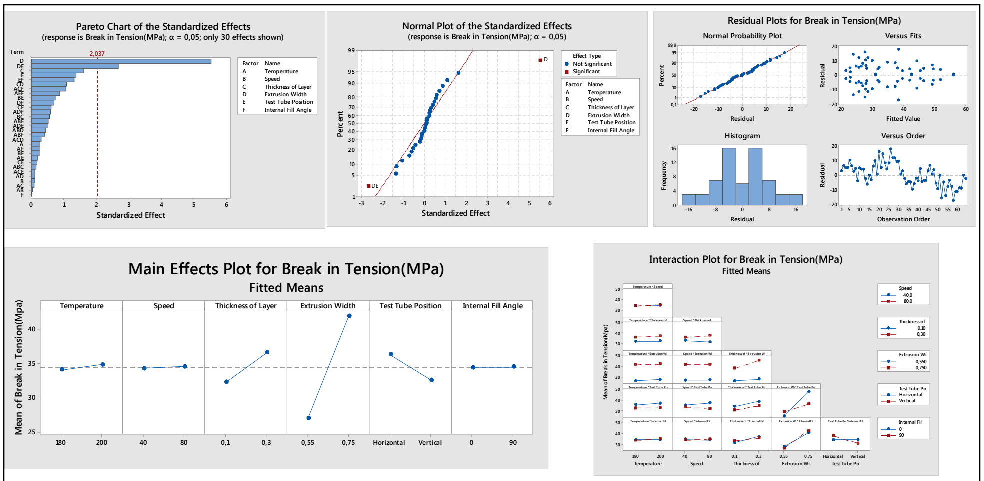
Model for Young (GPa) = -36,4 + 0,209 Temperature + 0,394 Speed + 63,8 Thickness of Layer + 39,6 Extrusion Width - 4,09 Test Tube Position + 8,59 Internal Fill Angle - 0,00206 Temperature*Speed - 0,385 Temperature*Thickness of Layer - 0,208 Temperature*Extrusion Width + 0,0233 Temperature*Test Tube Position - 0,0487 Temperature*Internal Fill Angle - 0,740 Speed*Thickness of Layer - 0,315 Speed*Extrusion Width + 0,0412 Speed*Test Tube Position - 0,0592 Speed*Internal Fill Angle - 21 Thickness of Layer*Extrusion Width + 4,7 Thickness of Layer*Test Tube Position + 4,7 Thickness of Layer*Internal Fill Angle + 0,3 Extrusion Width*Test Tube Position -9,3 Extrusion Width*Internal Fill Angle - 1,31 Test Tube Position*Internal Fill Angle.

Figure 8 – Summary of Results for the First Response Young Modulus (GPa)

Second answer: Break in tension (MPa)

Figure 9 shows a summary of the results for the second answer: break in tension (MPa). A normal plot analysis indicates that D is located at the left side of the red line, which indicates that D has a positive effect. At the same time, DE has a negative impact on the response, referred to as a break in tension. The main effects graph shows that the lines are not parallel to the x-axis for thickness of layer (C), extrusion width (D), or test tube position (E); however, clearly, the effects are more visible for extrusion width (D), which is a significant variable for that response. With the highest mean of break in tension, the level of extrusion width is the highest level of the variable at 0.75 mm.

The variables of temperature, speed internal fill angle are in striking distance of the horizontal mean line in the mean effect graph. Therefore, interaction plot graphs are useful in determining which level they interact with. For temperature at the speed of 80 mm/sec, the interaction graph has the highest mean, so, the temperature is 200ºC. As mentioned, DE has at significant effect on the response break in tension. When the interaction graph is displayed according to understanding of the integrated effect while variable E is horizontal (symbolised by the blue line), variable D has the value 0.75 mm, which is the highest level of extrusion width.



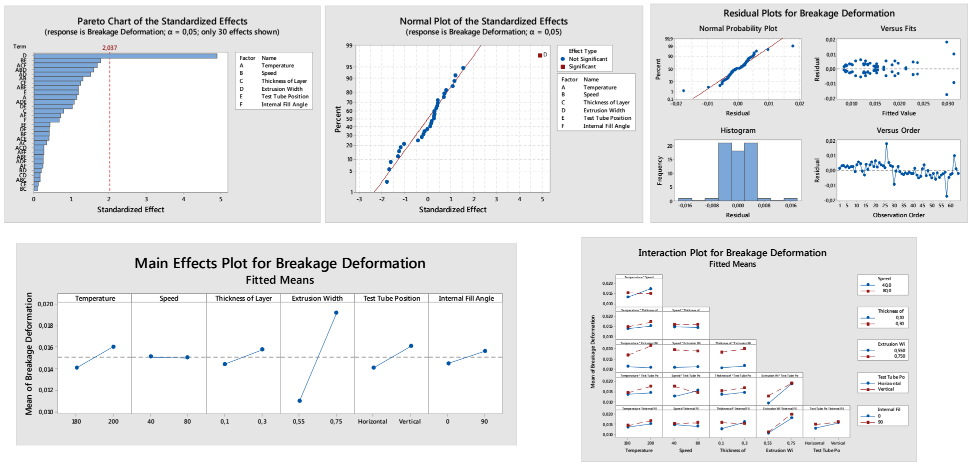
Model for break in tension (MPa) = 127 - 0,65 Temperature - 4,14 Speed + 275 Thickness of Layer - 105 Extrusion Width
+ 77 Test Tube Position+ 63 Internal Fill Angle + 0,0214 Temperature*Speed - 1,95 Temperature*Thickness of Layer + 0,80 Temperature*Extrusion Width-
0,27 Temperature*Test Tube Position - 0,36 Temperature*Internal Fill Angle + 2,3 Speed*Thickness of Layer + 5,6 Speed*Extrusion Width
+ 0,63 Speed*Test Tube Position - 0,50 Speed*Internal Fill Angle
- 639 Thickness of Layer*Extrusion Width - 33 Thickness of Layer*Test Tube Position+ 267 Thickness of Layer*Internal Fill Angle -
161 Extrusion Width*Test Tube Position- 142 Extrusion Width*Internal Fill Angle- 24,1 Test Tube Position*Internal Fill Angle

Figure 9 – Summary of Results for the Second Response Break in Tension (MPa)

Third answer: Breakage deformation

Figure 10 shows the summary of the results for the second and third answer: breakage deformation and break in tension (MPa). In the normal plot graph and Pareto chart, only extrusion width (D) has a significant effect on breakage deformation. Moreover, the main effect plot has an intense passing line, which belongs to the extrusion width. The line is not parallel to the X line. Process (D) has a positive standardised effect. When the process changes from a low level to a high level of the factor, the response increases. With the highest mean of breakage deformation, crucial variable D has a significant effect on response and must be 0.75 mm, which is the highest level of that variable.

In this interaction plot, the lines are not parallel. This interaction effect indicates that the relationship between temperature and speed depends on the value of the temperature range. For example, if the speed (B) 40 mm/sec is chosen, then temperature (A) 200ºC is associated with the highest mean breakage deformation. In other respects, if the speed 80 mm/sec is chosen, then the temperature 180ºC is associated with the highest breakage deformation.



Model for breakage deformation = 0,530 - 0,00286 Temperature - 0,00746 Speed + 0,15 Thickness of Layer - 0,877 Extrusion Width + 0,067 Test Tube Position- 0,045 Internal Fill Angle+ 0,000040 Temperature*Speed - 0,00080 Temperature*Thickness of Layer+ 0,00484 Temperature*Extrusion Width- 0,000298 Temperature*Test Tube Position+ 0,000234 Temperature*Internal Fill Angle+ 0,00132 Speed*Thickness of Layer+ 0,01267 Speed*Extrusion Width+ 0,000870 Speed*Test Tube Position+ 0,000226 Speed*Internal Fill Angle-0,42 Thickness of Layer*Extrusion Width- 0,064 Thickness of Layer*Test Tube Position+ 0,258 Thickness of Layer*Internal Fill Angle- 0,180 Extrusion Width*Test Tube Position- 0,036 Extrusion Width*Internal Fill Angle-0,0047 Test Tube Position*Internal Fill Angle

Figure 10 – Summary of Results for the Third Response Breakage Deformation

Phase 6: Improvement via confirmation experiments of the case study

The optimisation of the process response was carried out by pivoting the values of variable extrusion width (D) and test tube position (E) together as ‘DE’, which had a negative effect on the response. At the same time, D had an individual positive effect on the response. Thus, the variable level of E, which was founded ‘horizontal’, can alter into the ‘vertical’ by minimising the negative effect of ‘DE’ on the response. Other variables were not as significant as D. Therefore, any type of change in these variables would not affect the response as expected.

The software Minitab 18 allowed us to define the optimal level of the variables, taking into account all the answers. Figure 11 shows the levels to be programmed for each of the variables to maximise the results of all the responses. The proposed levels for all the answers were temperature (A) 180º C; speed (B) 40; thickness of layer (C) 0.3; extrusion width (D) 0.55; test tube position (E); and horizontal, internal fill angle (F) 0º. The expected results in these conditions for each response would be the following: breakage deformation 0.0022, break tension 56.20, and Young modulus 4.2.

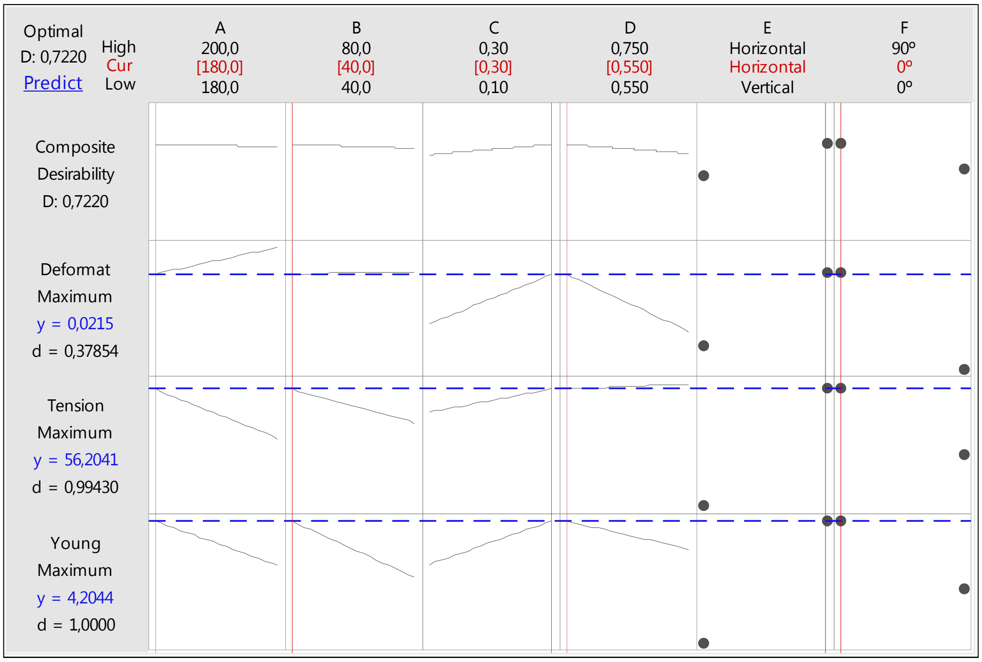


Figure 11 – Levels for Each of the Variable to Maximise All the Responses (Minitab 18)

Phases 7-8: Control and standardisation of the case study

Once the significant factors that affect the process were defined, and the levels that improve the response were indicated, the process was standardised by establishing controls to maintain the factors at the appropriate levels. Subsequently, the results were contrasted in the application of two real cases.

To validate and standardised the parameters identified in the study, the results were contrasted by manufacturing two moulds: one to manufacture skateboards (Figure 12) and one for drone cases (Figure 13) with the vacuum-assisted infusion process. Through this application, the validity of the identified parameters was verified since the manufactured modes were manufactured at the specified speed and quality levels.

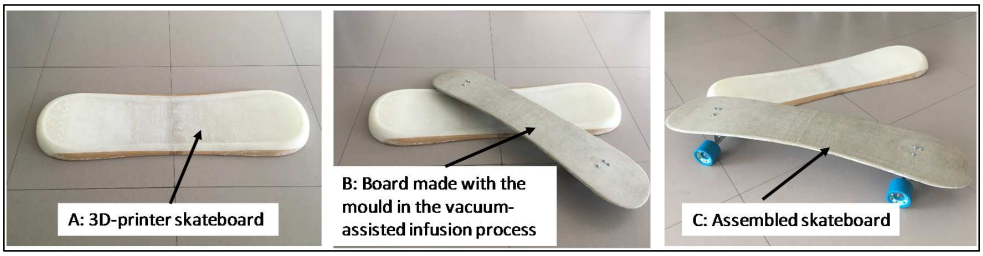


Figure 12 – Mould for a Skateboard

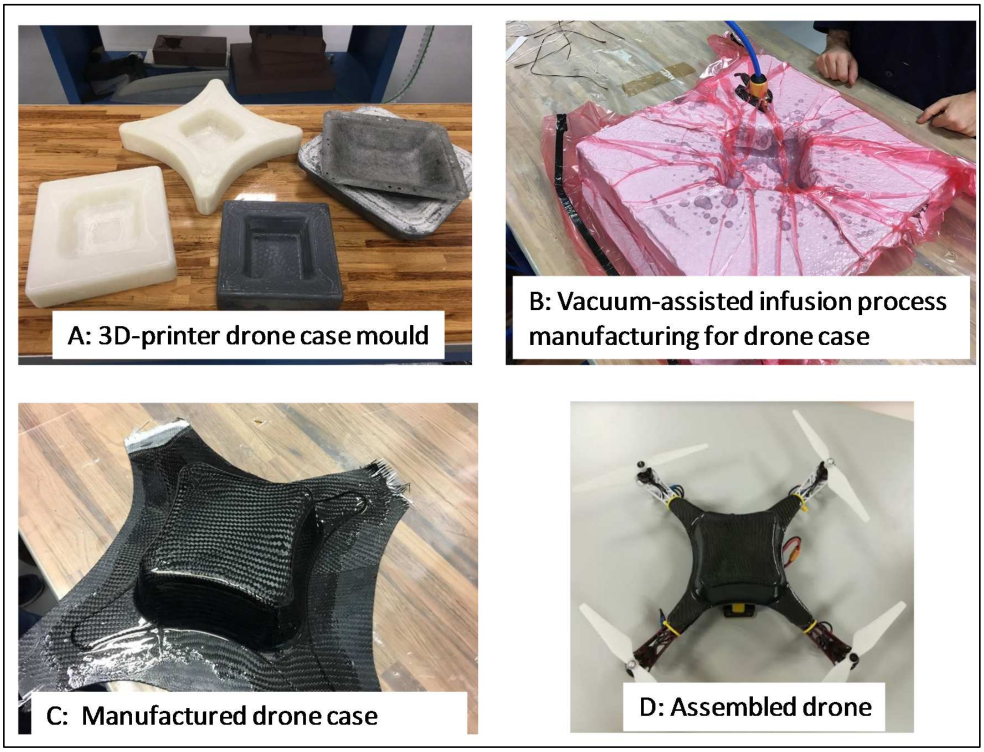


Figure 13 – Drone Case Mould

5 CONCLUSIONS

This article has demonstrated the importance of the use of experiment design methods to optimise methodologies through minimal experimental effort. It has also demonstrated the validity of the standard process followed by showing how to address the planned experimentation of any industrial process, enabling efficient use of the experimentation methods so that efforts to develop an understanding of the process are optimised. The applied methodology also allows for the development of the ability to deploy an appropriate experimental design to obtain maximum information with minimum experimental effort.

The best combination of levels for the three analysed outputs was identified, which was tested by manufacturing real products using the desired technical characteristics. The ideal combination is temperature (A) 180º C; speed (B) 40; thickness of layer (C) 0.3; extrusion width (D) 0.55; test tube position (E); and horizontal, internal fill angle (F) 0º. The results have been confirmed by their application in the manufacturing of two moulds applied in a vacuum-assisted infusion process. An analysis was carried out with the Minitab 18 statistical software to determine how the data might be exploited.

The same experimental setup and analysis techniques can be readily applied to different 3D technologies, and the corresponding best setting of the various control parameters can be obtained. The results of the case study provide a stimulus for the wider application of experimental techniques in organisations, which can use the steps of the presented methodology. Future research might consider how to carry out designs based on the proposed methodology in an iterative way that guides the execution of the experimental process sequentially, gradually acquiring knowledge based on previous experimentation.

REFERENCES

Anitha, R., Arunachalam, S. and Radhakrishnan, P., 2001. Critical parameters influencing the quality of prototypes in fused deposition modelling. *Journal of Materials Processing Technology*, [e-journal] 118(1–3), pp.385-388. DOI: 10.1016/S0924-0136(01)00980-3.

Chepelev, L., Giannopoulos, A., Tang, A., Mitsouras, D. and Rybicki, F.J., 2017. Medical 3D printing : methods to standardize terminology and report trends. *3D Printing in Medicine*, [online] Available at: <https://doi.org/10.1186/s41205-017-0012-5> [Accessed 31 March 2020].

Cruz, F.A., Boudaoud, H., Muller, L. and Camargo, M., 2014. Towards a standard experimental protocol for open source additive manufacturing. *Virtual and Physical Prototyping*, [e-journal] 9(3), pp. 37-41. DOI: 10.1080/17452759.2014.919553.

Dwivedi, G., Srivastava, S. and Srivastava, R., 2015. Analysis of Barriers to Implement Additive Manufacturing Technology in the Indian Automotive Sector. *International Journal of Physical Distribution & Logistics Management Rajiv*, 47(10). DOI: 10.1108/IJPDLM-07-2017-0222.

Gausemeier, J., Wall, M. and Peter, S., 2013. *Thinking ahead the Future of Additive Manufacturing – Exploring the Research Landscape.* [pdf] Paderborn: Heinz Nixdorf Institute. Available at: <https://dmrc.uni-paderborn.de/fileadmin/dmrc/Download/data/DMRC_Studien/DMRC_Study_Part_3.pdf> [Accessed 31 March 2020].

Gibson, I., Rosen, D. and Stucker, B., 2015. *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*. Second Edition. New York, NY: Springer. DOI: 10.1007/978-1-4939-2113-3.

Guo, N. and Leu, M.C., 2013. Additive manufacturing: Technology, applications and research needs. *Frontiers of Mechanical Engineering*, 8(3), pp.215-243.

Harris, R., 2019. Additive manufacturing research group. Loughborough University. Available at: <https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/> [Accessed 29 May 2019].

ISO (International Organization for Standardization), 2012. *ISO 527-2 Plastics — Determination of Tensile Properties — Part 2: Test Conditions for Moulding and Extrusion*. Geneva: ISO.

Ituarte, I.F., Coatanea, E., Salmi, M., Tuomi, J. and Partanen, J., 2015. Additive Manufacturing in Production: A Study Case Applying Technical Requirements. *Physics Procedia*, 78, pp.357-366.

Khajavi, S.H., Partanen, J. and Holmström, J., 2014. Additive manufacturing in the spare parts supply chain. *Computers in Industry*, [e-journal] 65(1), pp.50-63. DOI: 10.1108/RPJ-03-2017-0052.

Kumbhar, N.N. and Mulay, A.V., 2018. Post Processing Methods used to Improve Surface Finish of Products which are Manufactured by Additive Manufacturing Technologies : A Review. *Journal of The Institution of Engineers (India): Series C,* 99(4), pp.481-487.

Li, Q., Kucukkoc, I. and Zhang, D.Z., 2017. Production planning in additive manufacturing and 3D printing. *Computers and Operations Research*, 83, pp.1339-1351.

Lipson, H., Lyons, B., Bengio, S., Ochsendorf, J., Pyke, C., Leuthardt, E.C., and Weiland, J.D., et al., 2012. Manufacturing in Aerospace: Examples and Research. *Frontiers of Engineering,* [online] Available at: <https://www.nap.edu/catalog/13274/frontiers-of-engineering-reports-on-leading-edge-engineering-from-the> [Accessed 31 March 2020].

Moreau, C., 2018. *Annuaire Des Statistiques Des Hydrocarbures En Côte d'Ivoire*. [pdf] Ministère Du Pétrole,De L'énergie Et Du Développementdes Énergies Renouvelables. Available at: <http://dghstatistiques.ci/assets/documents/annuaire/Annuaire-DGH-2018-v3.pdf> [Accessed 31 March 2020].

Narang, R. and Chhabra, D., 2017. Analysis of Process Parameters of Fused Deposition Modeling (FDM) Technique. *International Journal on Future Revolution in Computer Science & Communication Engineering*, 3(10), pp.41-48.

Office of Technology Transition, 2019. *Additive Manufacturing: Building the Future*. Washington: Office of Technology Transition.

Prasad, M.M., Krishna, N.J. and Venkatasubbareddy, O.Y., 2014. Improving the Surface Roughness of FDM Parts By using Hybrid Methods. *International Journal of Engineering Research & Technology*, 3(12), pp.650-654.

Rayegani, F. and Onwubolu, G.C., 2016. Fused deposition modelling (FDM) process parameter prediction and optimization using group method for data handling (GMDH) and differential evolution (DE). *The International Journal of Advanced Manufacturing Technology*, [e-journal] 73, pp.509-519. DOI: 10.1007/s00170-014-5835-2.

Sood, A.K., Ohdar, R.K. and Mahapatra, S.S., 2010. Parametric appraisal of fused deposition modelling process using the grey Taguchi method. *Journal of Engineering Manufacture*, 24(1), pp.135-145.

Tofail, S.A.M., Koumoulos, E.P., Bandyopadhyay, A., Bose, S., O`Donoghue, L. and Charitidis, C., 2018. Additive manufacturing: scientific and technological challenges, market uptake and opportunities. *Materials Today*, 21(1), pp.22-37.

Unzueta, G., Orue, A., Esnaola, A. and Eguren, J.A., 2019. Metodología del diseño de experimentos. Estudio de caso, lanzador. *Dyna*, 94(1), pp.16-21.

Venkatasubbareddy, O.Y., Siddikali, P. and Saleem, S.M., 2016. Improving the Dimensional Accuracy And Surface Roughness of Fdm Parts Using Optimization Techniques. *IOSR Journal of Mechanical and Civil Engineering*, 16(053), pp.18-22.

Wiemer, H., Schwarzenberger, M., Dietz, G., Juhrisch, M. and Ihlenfeldt, S., 2017. A Holistic and DoE-based Approach to Developing and Putting into Operation Complex Manufacturing Process Chains of Composite Components. *Procedia CIRP*, 66, pp.147-152.

Wong, K.V. and Hernandez, A., 2012. A Review of Additive Manufacturing. International Scholarly Research Notices, [e-journal] 2012, 10p. DOI: 10.5402/2012/208760.

ABOUT AUTHORS

José Alberto Eguren – (J.A.E.) Mondragon University, Spain, Mechanical and Industrial Production department, e-mail: jaeguren@mondragon.edu, Author's ORCID: 0000-0002-4127-8776.

Aritz Esnaola – (A.E.) Mondragon University, Spain, Mechanical and Industrial Production department, e-mail: aesnaola@dumondragon.edu, Author's ORCID: 0000-0003-0955-7545.

Gorka Unzueta – (G.U.) Mondragon University, Spain, Mechanical and Industrial Production department, e-mail: gunzueta@mondragon.edu, Author's ORCID: 0000-0002-6889-3293.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this article. J.A.E., A.E and G.U. – conceptualization, resources, validation, writing review and editing.

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.