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TRENDS IN THE DEVELOPMENT OF THE ISO 9001 QUALITY MANAGEMENT SYSTEM – A PARAMETER OF THE LOGISTIC FUNCTION

Abstract

Objectives: The main objective of the article is to demonstrate that the number of ISO 9001 certificates issued can be modelled with high accuracy using a sum of logistic functions (multilogistic function). An attempt was also made to explain this phenomenon on the basis of the Triple Helix (TH) theory applied to the area of quality management.

Material and methods: In order to estimate the parameters of the logistic functions, normalized second-order logistic wavelets were used. The method allows specifying these parameters based on a scalogram – a graph of the Continuous Wavelet Transform (CWT) applied directly to the number of ISO 9001 certificates issued. Moreover, the authors discuss the theoretical model of the Triple Helix – the interaction of innovation with elements of the innovation system: globalization, competitive developments, and customer requirements in the context of the increase in the number of ISO quality management system certificates issued.

Results: Studies and calculations have fully confirmed that the number of ISO 9001 certificates between 1993 and 2022 can be effectively modelled using an appropriate multilogistics function. Using scalograms and CWT analysis, the type and position of successive logistic waves can be identified and their parameters can be estimated. This indirectly confirms that the Triple Helix theory is also applicable to quality management.

Conclusions: The possibility of using logistic wavelets, scalograms and, CWT analysis to detect logistic waves in time series related to quality management, has been confirmed. Once the parameters of the consecutive logistic waves have been estimated, the corresponding multilogistic functions can be used for forecasting.

Keywords: *Quality management, quality management system, ISO certification, Triple Helix theory, logistic wavelets.*

Introduction

Throughout history, the concept of quality has evolved to become today an important parameter in the management of organizations used to increase organizational efficiency, stakeholder satisfaction, create or strengthen competitive advantage. The term *quality* is a philosophical category, as the discussion of the general definition of quality dates back to antiquity and views on it were shaped by many works, e.g., I. Kant, G. Hegel, A. Descartes and J. Locke. Aristotle included quality in one of the ten descriptive categories of reality, claiming that it is *a set of peculiar characteristics that distinguish a given object from others*(Popescu, 2015).

Plato, on the other hand, believed that quality is the degree of perfection achieved by things. Leaving aside a review of the definition of quality, it can be said that it can be considered from the perspective of:

- engineering (control of production processes) – ability to, for example, use, meet requirements;
- marketing (degree of customer satisfaction, customer value);
- financial and economic (profits, losses, costs);
- human resources (efficiency, employee satisfaction);
- philosophical – degree of excellence;
- psychological – strengthening of relationships;
- ISO 9000:2015 – ability to satisfy customers and through intended and unintended impacts on relevant stakeholders.

Modern views on quality management are the product of both Japanese and American approaches to production and enterprise management. They have laid the groundwork for a change in thinking about quality management issues in both theory and practice. The term *quality management* arose as a result of economic and awareness changes in the world economy, as evidenced by the change in the approach to quality involving the following stages: quality supervision, quality control, quality assurance. The evolution of views on quality management should be combined with the development of organization and management theory. The period of industrial capitalism caused the development of the analytical current in management (so-called schools: classical, behavioural or quantitative current), which justifies understanding quality management in terms of supervision and control. The period of the developed market caused the development of the integrative current in management (the so-called positional school, resource or approaches: systemic, process, situational), which justifies understanding quality management in terms of quality assurance. On the other hand, the term *quality management* should be associated with the period of globalization, which can be understood both in the perspective of the concept of Total Quality Management (TQM) and the quality management system developed by the International Organization for Standardization (ISO). The aforementioned periods of development of organization and management theories directly link to the evolution of enterprise theories, which have direct links to quality management in both TQM and ISO terms, e.g. theory:

- evolutionary justifies the application of the principle of customer orientation;
- managerial justifies the application of methods and techniques;
- ecological justifies the application of the process approach principle;
- behavioural justifies the application of the leadership principle.

The presented relations of quality management with the theory of enterprise, organization and management indicate the integration of various concepts in quality management, as a result of the development of quality thought embedded in the context of combining good practices, patterns, models with the practice of quality management. Therefore, in general, it can be said that the concept of TQM means an approach to management in all aspects, levels, spheres of activity of the enterprise both internal and external, using existing (and emerging) concepts, systems, methods, which are oriented to the broad improvement of the organizational environment for the benefit of all stakeholders. In contrast, an ISO 9001 quality management system refers to *the activities by which an organization identifies its objectives and defines the processes and resources required to achieve the desired results and manages the interrelated processes and resources required to deliver value and results to relevant stakeholders and provides the means to identify activities that address the intended and unintended consequences of delivering products and services*(EN ISO 9000, 2015, p.6). It should be noted that the scope of the characteristics of the TQM concept is much broader than the ISO 9001 quality management system, which is concerned with meeting the following requirements; the context of the organization, leadership, support, operational activities, performance evaluation and accomplishment. A special feature of the system in question is the possibility of obtaining a certificate issued by a certification body, which the company can use for both marketing and commercial purposes (establishment, execution of contracts). The first edition of the standard containing the requirements of the quality management system took place in 2001 (ISO 9001). In subsequent years (2010 and 2015) ISO published revisions of the quality management system requirements.

Science, technology and innovations are the major drivers of sustainable economic development of countries in post-industrial economy. Economic growth increasingly relies on innovation activity (OECD, 2018). Continuous innovations are generated via collaborative and interactive relationship of economic agents, policy makers, science research organizations, and other innovation system participants. Innovation system can be considered as complex evolving or complex adaptive system due to non-linear mechanisms, which drive innovation system dynamics, feed-forward and feed-back loops of communications, adaptability to changing environmental conditions, (e.g. Russell and Smorodinskaya, 2018), otherwise also called as economic eco-system.

The most important property of innovation system is its effectiveness. Measuring the effectiveness of innovation system is of primary concern to researches and policy makers. Effectiveness can be measured quantitatively with respect to specific representation of innovation system, such as e.g. Triple Helix (TH) model of innovations (Etzkowitz and Leydesdorff, 1995). TH model explains the phenomenon of creating and introducing innovations via interaction of three major actors: University-Industry-Government. *Alongside the neo-institutional model of networked relations among universities, industries, and governments, the triple helix can be provided with a neo-evolutionary interpretation as three selection environments operating upon one another: markets, organisations and technological opportunities. How are technological innovation systems different from national ones? The three selection environments fulfill social functions: wealth creation, organisation control and organised knowledge production. The main carriers of this system – industry, government and academia – provide the variation both recursively and by interacting among them under the pressure of competition. Empirical case studies enable us to understand how these evolutionary mechanisms can be expected to operate in historical instances* (Leydesdorff and Zawdie, 2010). A system with three sub-dynamics can endogenously generate complex non-linear dynamics (Ivanova and Leydesdorff, 2014). In the framework of TH model, the phenomenon of the emergence of innovations can be described by means of logistic functions. Ivanova (2022) has shown that the Korteweg – de Vries (KdV) equation naturally appears in TH model. TH metaphor is also applicable to other fields such as the COVID-19 pandemic spread, financial markets, and rumors propagation.

The purpose of the present paper is to determine the parameters of the consecutive logistic functions (so called multilogistic function), modelling the number of ISO 9001 certificates from 1993 to 2022. Second-order logistic wavelets were used as a tool for estimating the parameters of the mentioned logistic functions. The subject scope of the study is ISO 9001 quality management system certificates, which includes all companies with ISO 9001 quality management system certificates in the world.

An attempt was also made to explain this phenomenon on the basis of the Triple Helix (TH) theory applied to the area of quality management.

1. International Organization for Standardization

The International Organization for Standardization was established in 1946. Its purpose is to promote the development of standardization and related activities worldwide in order to facilitate the international exchange of goods and services, improve the management of business processes, promote the dissemination of social and environmental best practices, and develop cooperation in the spheres of intellectual, scientific, technological and economic activities . ISO has 168 members , which are national standards bodies that have the status of member: full (influencing ISO strategy and actively participating in the work of ISO organizational units), correspondent (able to participate in the work of ISO organizational units as an observer), subscriber (informed about the work of ISO organizational units). ISO 9001:2015 defines the requirements for a quality management system. It is used to:

- demonstrate the organization's ability to consistently deliver products and services that meet customer requirements and applicable statutory and regulatory requirements;
- enhance customer satisfaction through the effective application of the system, including processes for system improvement and ensuring compliance with customer requirements and applicable statutory and regulatory requirements.

All the requirements of ISO 9001:2015 are general in nature and are intended to apply to any organization, regardless of its type or size, and the products and services it provides.

2. The Triple Helix model in ISO innovation

Since management and quality sciences are part of the social sciences, an assumption can be made about the possibility of extending the application of the Triple Helix model in these sciences. Analysing the changes in the content of ISO 9001, it can be said that they were related to the increase in quality requirements at both the macroeconomic and microeconomic levels. Examples of the reasons for the growth of quality requirements in the economy are: legal regulations (e.g.: consumer or environmental protection, responsibility for quality), growth of customer expectations (e.g.: additional functions of products, reliability, ease of use), competitive struggle (e.g.: entrepreneurship, innovation, cost strategies), strategic goals of enterprises (e.g.: value growth, risk reduction, uniqueness of products and services). On the other hand, examples of reasons for the growth of quality requirements at the microeconomic level are: state institutions (e.g.: application of laws, e.g. consumer protection, environment, market), customers (e.g.: deadline, price, reliability, availability, safety), employees (e.g.: working conditions, development, participation, valorisation), suppliers or co-operators (e.g.: partnership, relations, timeliness). The examples presented for the growth of quality requirements can be related to three dimensions: globalization, competition and customer requirements. Globalization *consists of the multiplicity of links and interactions of states and societies that make up the current world system*(McGrew, 1992, p.28) therefore it is the result of the evolution of long-term and complex processes in national economies. In this context, globalization is *the historical process of liberalization and the progressive integration of hitherto operating in some isolation of markets for capital, goods and labour into a single interdependent world market*(Van Der Bly, 2005). Globalization can be understood in various aspects, as: the international mobility of capital, the development of technology and related research and knowledge, the unification of lifestyles, consumption patterns or culture, or the unification of governance and regulation. This justifies the multiplicity of generic classifications of globalization, the dimensions of which are, for example, social, political, economic, cultural, ecological, technical. The KOF Index of Globalization is used to measure the degree of integration of the world's countries in social, economic and political aspects. Analytical indicators of globalization can include:

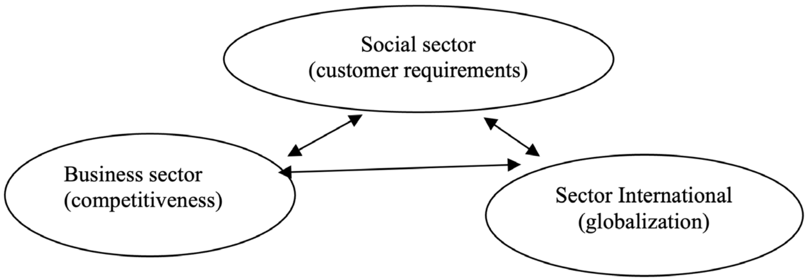
- economic (World Development Indicators);
- social – the Human Development Index, the index of social inequality ;
- competitiveness (The Global Competitiveness Report);
- economic freedom (Index of Economic Freedom).

Under the influence of globalization, the tendency to produce technological and innovative knowledge in the laboratories and institutes of large multinationals has intensified, which, on the one hand, has weakened the position of public academic institutions in technological knowledge and, on the other, has increased the market significance of this knowledge. This has had significant implications for the creation of competitive advantages, the sources of which include (Malik, 2019), (Wang at al, 2011):

- the speed of creation and development or upgrading of products with global reach,
- world-class manufacturing meaning the use of modern technology, equipment and production organization that enables the structure and volume of supply to be adapted to the structure and volume of demand,
- global marketing that ensures both customer satisfaction and enables effective product introduction into target markets,
- ability for high financial accumulation, enabling concentration on activities providing the highest added value.

In this regard, it can be said that the technical dimension of globalization is related to the competitiveness of enterprises. It can be understood as the effect of competing in the customer market expressing the ability of a given enterprise to provide customers with the values they desire at the right time and place in a more efficient and effective way than competitors. The increase in customer demands is justified by the knowledge and experience with the product created from the company's own experience. Meeting customer requirements means for the company to create new products and services, which requires the introduction of innovations (e.g. product, process, organizational). Based on the considerations presented, it can be said, the common element of the dimensions of the growth of quality requirements is innovation, which combines the dimensions of globalization, competition and customer requirements. At the same time, the described relationships indicate the applicability of the model of the interaction of the fields of the Triple Helix , in which the dimensions are characterized by a relatively independent status, but there are advanced interactions between them, as shown in Fig. 1

Figure 1. *A model of the interaction*



Source: own elaboration.

The listed examples of the increase in quality requirements can be considered as the basis for the introduction of innovations in ISO quality management system requirements. The rationale is the characteristics of the changes introduced, for example: introduction of: process approach, business orientation, customer orientation, principle of continuous improvement, increase in leadership requirements, introduction of change and knowledge management elements. Assuming that the quality management system is an ISO product, and considering the following definition of innovation: a new or improved product introduced to the market or a new or improved process applied in production, whereby this product or process is new at least from the point of view of the company introducing it, the innovations introduced by ISO are organizational in nature.

3. Wavelets

Wavelets are mathematical functions used in the analysis of signals, time series and images. They are a special type of basic functions that are localized in time and frequency. Each wavelet is derived from the basis function using shifting and dilating. Their characteristic feature is the ability to present signals in both the time and frequency domains. This means that they can be effectively used to analyze signals with varying frequencies over time. The main advantage of wavelets is their ability to represent both fast and slow changes in a signal, which makes them more versatile than traditional harmonic functions such as sine waves.

The mathematical foundations of the wavelet theory is given in many sources. The basic and often cited study is the book by Daubechies (1991) . A wavelet or mother wavelet (Daubechies, 1991 p. 24) is called an integrable function for which there is a certain admissibility condition, reducing in practical applications to the condition of vanishing of the integral of $\psi(t)$:

$$\int_{-\infty}^{\infty} \psi(t) dt = 0$$

Using the mother wavelet, through dilations and shifts, a doubly indexed family of wavelets (so called children wavelets) expressed by the formula is obtained:

$$\psi^{a,b}(t) = \frac{1}{\sqrt{|a|}} \psi\left(\frac{t-b}{a}\right)$$

where $a, b \in R, a \neq 0$. Continuous wavelet transform (CWT), for a given family of wavelets, is defined as:

$$(\mathrm{T}^{\mathrm{wav}} f)(a,b) = \int_{-\infty}^{\infty} f(t) \psi^{a,b}(t) dt$$

As a result of applying the CWT transform, scalograms, also called heat maps, are obtained, allowing the detection of appropriate patterns in the analyzed time series or another signal and the estimation of the parameters of approximating functions. There are different types of wavelets, examples of which are: Haar, Daubechies, Gaussian, Morlet, Meyer, Mexican Hat, Logistic, Gompertz (e.g., Daubechies, 1991; Meyer and Ryan, 1996; Meyer, 1997; Rządkowski, 2024)

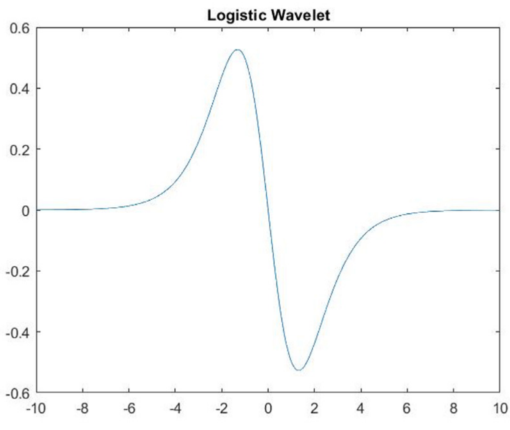
4. Presentation of research results

4.1. Description of the research method

The study used second-order logistic wavelets (Rządkowski and Figlia, 2021) and Rządkowski (2023, preprint), for which the normalized (the norm in the space of square integrable functions equals to one) mother function (Fig. 2) is expressed by the following formula (here *e* denotes the Euler constant, the base of natural logarithm):

$$\psi_2(t) = \frac{\sqrt{30}(e^{-2t} - e^{-t})}{(1 + e^{-t})^3}$$

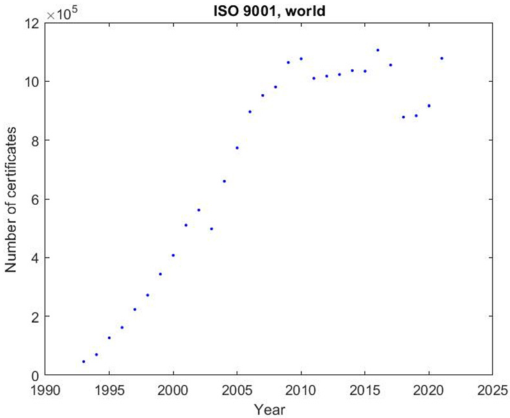
Figure 2. *Second-order logistic wavelet*



Source: Own elaboration in MATLAB

The study covered the number of quality management system certificates issued by ISO 9001 in the years 1993 – 2022, the distribution of which is shown in Fig. 3.

Figure 3. *Number of ISO 9001 certificates issued in the years 1993 – 2022*



Source: own elaboration in MATLAB based on: https://www.iso.org [Accessed: 15 March 2024].

In order to confirm the hypothesis about the possibility of approximating (modelling) of the number of ISO 9001 quality management system certificates issued in the years 1993 – 2022 a multilogistic function of the form

$$f(t)=\sum_{i=1}^{k}\frac{x_{i,max}}{1+\exp\left(-\frac{t-b_i}{a_i}\right)}$$

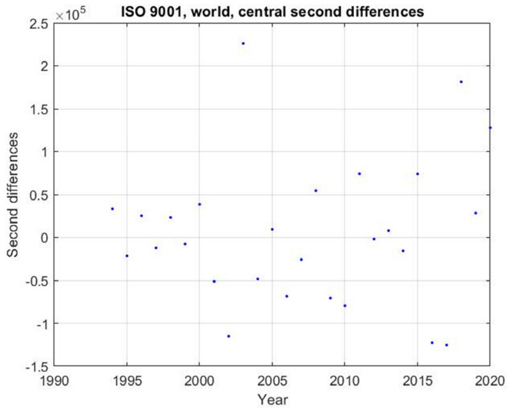
has been applied, the parameters (a_i, b_i, $x_{i\,max}$) of which are estimated by using the logistic wavelets, scalograms and the CWT analysis.

To estimate the parameters of the multilogistic function, CWT analysis was used for the time series of the number of ISO 9001 quality management system certificates issued in the years 1993 – 2022 (n=1 (1993), n=29 (2022)). The central second differences of this time series were applied, utilizing the method described in Rządkowski and Figlia (2021) for a normalized second-order mother logistic wavelet. Due to the specificity of this method, there were calculated the central second differences by formula:

$$\Delta^2 y(n)=y(n+1)-2y(n)+y(n-1)$$

4.2. Results

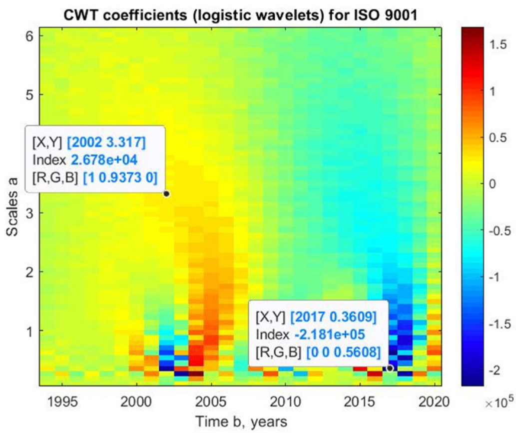
Figure 4. *Central second differences*



Source: own elaboration in MATLAB

For the second differences $\Delta^2\, y(n)$ (Fig 4.) the CWT was applied using a normalized second-order logistic wavelet $\psi_2\,(t)$. The scalogram with two main logistic waves and their initial parameters is presented in Fig. 5.

Figure 5. *Scalogram with initial parameter values of two logistic waves*



Source: own elaboration in MATLAB.

For the increasing wave (year 2002, n=10) the value of the parameters are estimated and b = 10 and a = 3,32. The maximal value of the Index (Index=26780) allows to estimate the saturation level x_{max} = 887316, based on the following calculations (Rządkowski i Figlia, 2021):

$$x_{max} \approx \sqrt{30} \cdot a^{\frac{3}{2}} \cdot \text{Index} = \sqrt{30} \cdot (3.32)^{\frac{3}{2}} \cdot 26780 = 887316$$

After optimizing the saturation level x_{max} and parameter a to minimize the RMSE error:

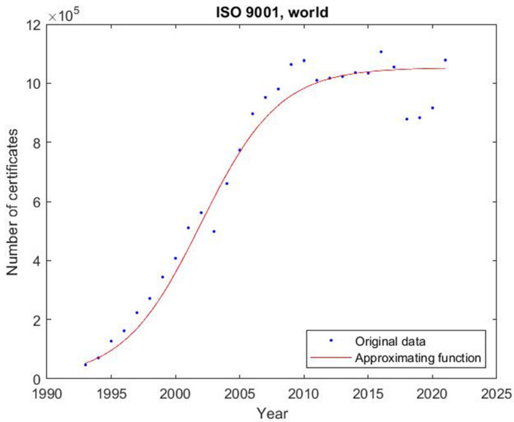
$$\text{RMSE} = \sqrt{\frac{1}{29}\sum_{n=1}^{29}\left(y(n) - f(n)\right)^2}$$

one gets a single logistic wave (shown in Fig. 8) of the form:

$$f(t) = \frac{1{,}053{,}297}{1 + e^{-\frac{t-10}{3.04}}}$$

approximating the values observed with error RMSE=70,618.

Figure 6. *Approximation by a single logistic function*



Source: own elaboration in MATLAB.

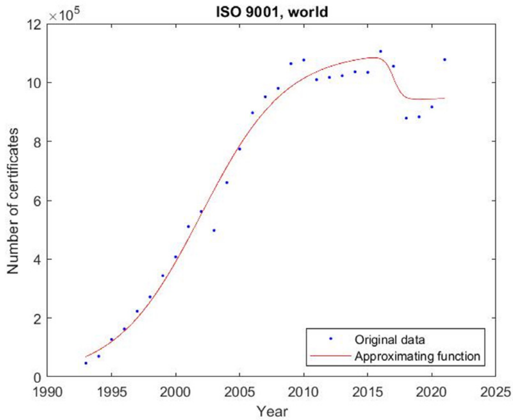
The observed values were then approximated using the sum of two logistic functions, the second of which has a negative index value and is decreasing.

After performing the calculations, an approximating function of the form was obtained:

$$f(t) = \frac{1{,}105{,}088}{1 + e^{-\frac{t-10}{3.32}}} - \frac{155{,}926}{1 + e^{-\frac{t-25}{0.36}}}$$

with error RMSE=52,090 (shown in Fig. 7).

Figure 7. *Approximation by a double-logistic function*



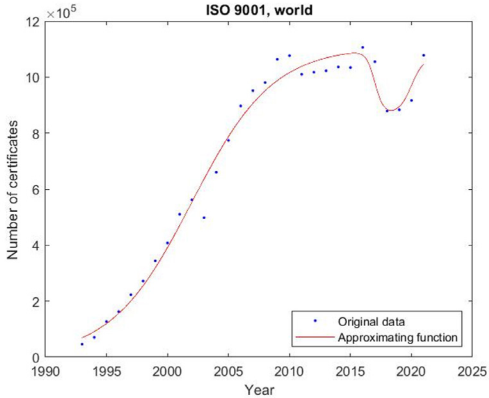
Source: own elaboration in MATLAB.

In order to better match the approximating function to the final observed values, the increasing wave appearing in Fig. 5 for 2022 (n = 28) was taken into account. After performing the calculations, the following form of the multilogistic function was obtained:

$$f(t) = \frac{1{,}107{,}287}{1 + e^{-\frac{t-10}{3.32}}} - \frac{230{,}421}{1 + e^{-\frac{t-25}{0.36}}} + \frac{196{,}321}{1 + e^{-\frac{t-28}{0.5}}}$$

with error RMSE=45,535 (Fig. 8).

Figure 8. *Approximation by a triple-logistic function*



Source: own elaboration in MATLAB.

Summary

The Triple Helix theory shows that three factors influence the emergence, development and introduction of innovation: universities (science, knowledge), industry and governments (administration). These factors and their interaction can affect the innovation positively or negatively. One of the conclusions of this theory is the occurrence of logistic curves in innovation-related phenomena. Attempts are currently underway to apply the TH approach to various fields of science and practice.

The theoretical model of the Triple Helix in the area of quality management presented in the article required the following assumption: with regard to quality management, the trends in the development of the application of ISO 9001:2015 by enterprises were shaped by groups of factors (globalization, development of competition, customer requirements). It allowed us to apply logistic curves and conduct wavelet analysis, the results of which entitle us to conclude that the development of the application of the ISO 9001:2015 quality management system in enterprises can be modelled using multilogistic functions. The benefits of modelling by means of multilogistic functions apply both to the International

Organization for Standardization and to companies using the quality management system in business practice. In addition to confirming the legitimacy of the function, the ISO has the opportunity to innovate by adapting the content and scope of standards to market needs (both expressed by companies and their customers). Another aspect is the ability to prevent companies from using market practices that are negative for customers. Thus, ISO can continue to shape the quality management system approach. The benefits for companies are the continued use of ISO 9001:2015 for: internal (improving the management system and product quality), as well as external (competing in both local and global markets). The benefits listed are direct.

Indirect benefits of modelling by means of multilogistic functions also apply to the customers of companies using ISO 9001:2015 through the concern of companies to ensure that the identified needs, expectations and requirements of customers are met, which is clearly implied in section 4.2 of ISO 9001:2015 – understanding the needs and expectations of stakeholders, including customers. Other dimensions of benefits are: financial (sales revenue) for both ISO (applies to ISO 9001:2015) and enterprises (applies to products), marketing (strengthening e.g.: brand, image, market or bargaining position). A promising direction for further work is the study of the theoretical Triple Helix model on other ISO standards used by enterprises (e.g. ISO 14004, EN-ISO 22000). Confirmation of the existence of an equal form of the multilogistic function would provide evidence of a new application of triple helix models in all areas of quality management covered by the International Organization for Standardization.

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