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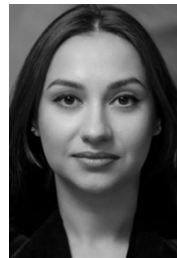
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SYSTEM ANALYSIS OF THE COMMUNICATION PROCESS WHEN IMPLEMENTING THE ISO 9001 STANDARD IN SOCIO-ECONOMIC SYSTEMS

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ABSTRACT:

This study addresses the critical role of communication in implementing the ISO 9001:2015 standard within socio-economic systems, where complexity and dynamism make information exchange a decisive success factor. The research aims to develop a systematic approach for analysing and optimising communication processes in quality management systems (QMS). The methodology is based on systems analysis and graph theory, representing QMS elements as vertices and their interactions as edges. This formalisation enables the identification of weak links, isolated or overloaded components, and critical communication nodes. Key indicators such as connectivity, rank, articulation points, and survivability were applied to evaluate system robustness, particularly at the design stage, where errors are most costly. The results demonstrate that graph-based modelling facilitates early risk detection, supports structural optimisation, and strengthens communication flows. The findings highlight the novelty of integrating qualitative management principles with quantitative graph analysis, offering organisations a proactive tool to enhance adaptability, reliability, and compliance with ISO 9001:2015.

KEYWORDS:

communication networks, digital communication, internal and external communication, ISO 9001:2015, organisational communication, organisational adaptability, quality management, socio-economic systems, strategic communication, transparency and trust

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1 Introduction

In today's era of globalisation and rapid technological advancement, socio-economic systems encounter new challenges in quality management. One of the key tools for ensuring the sustainable development of organisations is the adoption of international standards, particularly ISO 9001, which outlines requirements for a quality management system (QMS). However, implementing this standard demands not only technical adjustments but also significant enhancements in management and communication mechanisms.

Communication is a critical factor in the successful operation of a QMS, as it facilitates coordination across all organisational levels, promotes effective delegation of responsibilities, reduces the risk of erroneous decisions, and enhances overall trust. However, in socio-economic systems characterised by multi-layered structures, numerous stakeholders, and constant change, communication processes are often complex. Therefore, a systematic approach to analysing communication during the implementation of ISO 9001 is essential to identify weaknesses, optimise information flows, and ensure compliance with the standard's requirements.

The purpose of this article is to conduct a systematic analysis of the communication process within socio-economic systems during the implementation of the ISO 9001 standard.

2 Literature Review

Research in management and organisational studies emphasises that communication is not only a technical process of information transfer, but also a complex social phenomenon that actively shapes the effectiveness, identity, and culture of an organisation (Izak et al., 2024; Abdelfettah & Hamza, 2025). Effective communication is associated with improved leadership, team dynamics, decision-making, and overall organisational effectiveness, while clear and transparent channels promote trust and interaction between stakeholders (Musheke & Phiri, 2021). Communication practices are also seen as strategic resources that strengthen organisational identity, support sustainable development, and build stakeholder trust (Cooren & Seidl, 2020). Theoretical approaches, including systems theory and critical perspectives, further emphasise the importance of communication in ensuring collaboration, adapting to change, and challenging hierarchical structures to promote more symmetrical and reciprocal relationships within organisations (Nicotera et al., 2019). Recent research calls for greater attention to paralinguistic aspects, the integration of communication with real-world work practices, and the study of communication in different cultural contexts to deepen our understanding of its multifaceted role in organisations (Abdelfettah & Hamza, 2025).

Research highlights the crucial role of internal communication in promoting innovation, collaboration, and knowledge sharing within organisations. Internal communication, especially when transparent and strategic, increases employee satisfaction and promotes knowledge sharing, which is essential for innovation, particularly during crises such as the COVID-19 pandemic. Knowledge sharing itself is a key prerequisite for innovative behaviour, and communication with management and colleagues are important drivers of this process (Koivumäki & Wilkinson, 2020; Lee et al., 2020).

The internalisation and externalisation of tacit knowledge, which often develops through “learning by doing” or “learning by interacting”, largely mediates the link between knowledge acquisition and innovation outcomes, and these processes can be influenced by national and organisational contexts (Zhao et al., 2021). Ethical communication and prosocial engagement further enrich the innovation process. Ethical behaviour not only directly supports

innovative work behaviour, but also does so indirectly by facilitating knowledge sharing, while the ethical climate in organisations mediates the link between knowledge sharing and innovation (Khorakian et al., 2019). Prosocial motivation, which involves actions for the benefit of others, has been shown to mediate the impact of certain types of motivation on knowledge sharing, suggesting that promoting a prosocial and ethical climate can improve both knowledge sharing and innovation (Göhler et al., 2022). As organisations face increasing complexity and challenges such as disinformation, the integration of ethical, prosocial, and transparent communication practices is becoming increasingly important for supporting innovation and collective intelligence (Derin et al., 2021).

In contemporary scientific discourse, there is a growing need for a comprehensive approach to managing socio-economic systems due to their increasing complexity, dynamism, and the uncertainty of the external environment. In this context, the systematic analysis of complex systems is a fundamental concept that enables the identification of interrelationships amongst individual elements, processes, and influences within organisations and society as a whole. Systematic analysis of complex systems facilitates the study of systems with numerous interconnected elements, where global behaviour cannot be directly derived from the properties of individual components. The primary characteristics of complex systems include non-linearity, emergence, multi-level structures, and adaptability (Ladyman et al., 2020; Siegenfeld & Bar-Yam, 2020). Various mathematical models, such as network analysis, agent-based modelling, statistical and machine learning methods, and big data analysis, are employed to analyse such systems (Boers et al., 2021; Szabo, 2024). A critical aspect is the development of models that evaluate both static and dynamic properties of the system while accounting for complex interdependencies amongst elements (Chakrabarti et al., 2023; Steigmann, 2024). Modern approaches also incorporate machine learning and network analysis to identify patterns in complex data, for instance, in climatology, biology, or social networks (Boers et al., 2021; Chakrabarti et al., 2023). Recent studies highlight the importance of reducing model dimensionality to better understand the global behaviour of the system while preserving key interactions (Thibeault et al., 2024). Systematic analysis of complex systems helps elucidate how local interactions lead to global effects, enabling the development of effective strategies for managing and predicting the behaviour of such systems (Kasman et al., 2021).

The development of systems thinking in management practice is directly reflected in quality management models, particularly in the application of the ISO 9001:2015 standard, which is amongst the most widely adopted globally. Analysis of the quality management system under ISO 9001:2015 reveals that the standard is grounded in a process-oriented approach, risk management, and principles of continuous improvement, enabling organisations to achieve their objectives effectively and enhance competitiveness (Kowalczyk, 2024; Limón-Romero et al., 2024). Key factors for successful implementation include leadership and engagement of top management, a robust quality culture, standardised procedures, and increased staff awareness (Bravi et al., 2019; Bouchetara et al., 2022; Sherwani et al., 2025). Research indicates that the primary benefits of adopting ISO 9001:2015 include enhanced customer satisfaction, improved internal processes, and a strengthened organisational reputation, though challenges such as resource constraints, insufficient staff training, and resistance to change may arise (da Fonseca et al., 2019; Pathan et al., 2021). For small and medium-sized enterprises, internal and external support, as well as the adaptation of documentation to company-specific needs, are particularly critical (Arslan et al., 2023; Renosori et al., 2023). Assessing the maturity of a quality management system enables organisations to determine the current level of compliance with the standard and identify areas for further improvement (Anggraeni 2022; Tarigan & Rajagukguk, 2023). The practice of implementing the standard confirms that systematic analysis, staff training, and regular process reviews contribute to achieving high performance and certification (Darmadi & Setiawan, 2021).

These advancements in quality management directly underscore the importance of communication processes within organisations. ISO 9001:2015 explicitly requires organisations to define what, how, when, and with whom to communicate within the quality management system. Studies demonstrate that implementing this quality management system not only maintains product quality but also significantly enhances the structure of organisational communication (Özkan, 2021). Companies operating under the ISO 9001:2015 standard exhibit improved employee interactions, a clearer understanding of roles and responsibilities, and more effective fulfilment of customer and partner needs (Stevanovic & Gmitrović, 2015). Some authors (e.g., da Fonseca et al., 2019) note that effective communication serves as a central tool in ensuring process transparency, engaging staff in achieving quality

objectives, and fostering conditions for organisational self-learning. Thus, communication evolves from an instrumental function into a key systemic factor.

This approach is particularly significant in the context of socio-economic systems, where communication serves not only as a technological tool but also as a social phenomenon that shapes the trajectory of societal development. Research indicates that effective communication enhances action coordination, resource mobilisation, partnership formation, and system resilience, particularly in crisis situations such as disaster recovery (Miller et al., 1998; Rozikin, 2024). In the era of digitalisation, communication is acquiring new characteristics: the importance of interactivity, multimedia, and information accessibility is increasing, yet challenges related to unequal access to technology persist (Hutchinson & Ahmad, 2024). Within organisations, internal communication boosts employee motivation, facilitates conflict resolution, and fosters innovation (Battistón et al., 2020; Ruão et al., 2022). Effective communication also underpins knowledge management, transforming individual expertise into collective intelligence and enhancing competitiveness (Losana & Gallardo, 2019). Furthermore, communication plays a critical role in promoting social stability, aligning the interests of diverse groups, and contributing to national security (Jacobsen & Salomonsen, 2021). Innovative information and communication technologies are reshaping the structure of economic and social relationships, creating new opportunities for development while necessitating the adaptation of management strategies (Heide & Dahlman, 2020).

Thus, contemporary literature highlights a clear interdependence amongst systematic analysis, quality standards, communication management, and the effectiveness of socio-economic systems. These components are complementary, collectively forming the foundation for the adaptable and sustainable development of organisations amid global competition and instability.

3 Effective Communication as a Part of Quality Management System

Effective communication is a critical component of establishing a robust quality management system. Section 7.4 of the ISO 9001:2015 standard mandates that organisations streamline both internal and external communication processes by addressing five key questions: what, when, with whom, how, and who communicates. Each aspect is examined below.

The organisation must define the content of the communicated information. This may include the quality policy, quality objectives and key performance indicators, audit and inspection results, process-related risks and opportunities, changes in regulatory requirements or procedural documentation, customer inquiries, feedback, or staff suggestions. Communication should be purposeful, relevant, and aligned with the organisation's objectives. For instance, when introducing a new product, employees should receive clear information about quality requirements, technological processes, and service standards.

The timing or frequency of communication depends on the information's criticality, operational pace, and stakeholder needs. For example, strategic information may be shared during quarterly meetings, operational updates during daily planning sessions, procedural changes or instructions prior to their implementation, and incident or deviation reports immediately. Regular communication enables timely problem identification and maintains process control. Post-event communication is also vital for analysing causes and implementing corrective actions.

The standard requires identifying the communication audience, which may include internal parties such as employees across departments, management, and engineering or control personnel, as well as external parties like customers, suppliers, regulatory authorities, auditors, or the public. The level of detail and presentation style should vary based on the audience. For example, suppliers require specifications and raw material requirements, employees need safety protocols and operational procedures, and customers expect quality certifications or responses to complaints.

Communication channels should be diverse and include written formats (instructions, e-mails, reports), verbal methods (meetings, briefings, conferences), electronic platforms (internal portals, messaging apps, CRM systems), visual tools (posters, charts, information boards), and interactive methods (surveys, questionnaires, feedback platforms). The chosen format must be accessible and suitable for the target audience, considering the organisation's communication culture and technical capabilities. For instance, in multinational companies, using English or universally understood visual standards is advisable.

The organisation must clearly designate individuals or departments responsible for specific communications, such as quality managers, department heads, area-specific personnel, or internal communications and HR specialists. A clear allocation of responsibilities prevents message duplication, information loss, or misinterpretation. This is particularly critical for external communications, where official interactions with regulatory authorities or customers should be handled by authorised representatives.

In scientific and applied literature, the implementation of ISO 9001 is often examined through the lens of process documentation, risk assessment, or management efficiency. However, communication is frequently underexplored or narrowly interpreted as mere information transfer between organisational units. This limited perspective fails to capture the complexity of interrelationships within socio-economic systems during standard implementation.

In this context, systematic analysis is an essential tool for studying communication processes. It enables comprehensive examination of all elements within the communication environment, including information flow structures, interaction channels, participant roles, feedback mechanisms, and sources of interference. A systematic approach reveals hidden cause-and-effect relationships, identifies bottlenecks in information exchange, assesses the effectiveness of communication strategies, and provides recommendations for optimisation.

Thus, conducting a systematic analysis of communication processes during the implementation of the ISO 9001 standard in socio-economic systems is a justified necessity. It facilitates a holistic understanding, enhances the effectiveness of quality management, and enables organisations to adapt to the dynamic conditions of internal and external environments.

A quality management system is a comprehensive framework comprising management methods, functions, material and technical resources, information systems, and human resources. Through these components, the managing entity influences the managed object to achieve specific objectives. A single management system may consist of varying numbers of elements, which can differ in quality and interact differently with each other and the production process. Management activities, decision-making processes, and information collection and processing can be organised in diverse ways, employing various technical tools and management methodologies.

The managing entity may include differing numbers of employees, with varying ratios of managers to subordinates, senior to junior specialists, and other categories of management personnel. Additionally, individual management units within a system may have distinct responsibilities for the outcomes of their activities and exert varying degrees of influence on production management processes. These units may also differ in the complexity of their functions, resource consumption, and the qualifications of personnel, including their education, work experience, and professional capabilities. Each individual's abilities shape their approach to their duties, with the realisation of these abilities depending on the appropriateness of personnel selection, placement, and training. Furthermore, management positions vary in the complexity of duties, responsibilities, remuneration, and other characteristics.

The QMS of an enterprise encompasses a set of activities that align with international standards (ISO 9001, 2015; ISO 9004, 2018). Each process within the QMS can be broken down into subprocesses or individual operations. These processes and subprocesses integrate various resources – such as labour, equipment, information, materials, and energy – through communication channels to achieve desired outcomes. In essence, the QMS is a functional structure where system elements, represented by processes, are interconnected through material and information-communication flows, all directed towards achieving established goals.

To develop an effective QMS, it is proposed to treat it as a large, complex system and apply appropriate analytical methods. Studying such systems requires analysing numerous communication links between elements and phenomena, conducting comprehensive research, and considering the interactions between parts and the whole, as well as the system's connections with its external environment.

Like any system, a QMS progresses through distinct stages: design, development, implementation, and improvement. Each stage is critical, but the design stage is particularly significant and resource-intensive, as it establishes the system's foundational model. Errors made during this stage are the costliest and challenging to rectify. Therefore, this article's focus on the systematic analysis of communication processes during the implementation of the standard (ISO 9001, 2015) in socio-economic systems at the design stage is highly relevant.

A defining characteristic of the initial design stage is the limited availability of information about the future system. The initial data typically include general requirements for the system's characteristics and a standard structural-functional diagram with a broad description of its operating principles.

The limited availability of initial information during the early design stages necessitates the use of models that are effective with minimal input data and supported by the available information. One such model is the system's structure combined with its set of communications. Structural analysis provides insights into the complexity and significance of system elements, enables comparison of systems with different structures, and identifies the system's "weak points", facilitating timely refinement of the system structure and adjustments to the quality assurance program.

Therefore, it is proposed to study the QMS at the design stage using the theory of relations (communications), which is grounded in structural studies based on graph theory. Analysis at this stage enables the development of rules for the symbolic representation of QMS elements, determination of the significance of these elements and their communications, evaluation of the quality of the QMS structural diagram, and formulation of recommendations for its improvement.

A system model, represented as a structural diagram, is a graphical depiction of system elements and their communications. This diagram allows the study of an object in its most general and abstract form. By focusing on identifying mutual communications between system elements, thereby prioritising the system's structure over the composition of its individual components, it becomes possible to analyse systems of varying natures uniformly. This approach facilitates the standardisation and unification of the QMS design procedure at the design stage.

According to communication theory, the set of communications amongst a given set of elements can be represented by matrices. These communication matrices serve as an analytical representation of a graph, while a graph can be viewed as a geometric representation of a communication matrix. This relationship allows the system's communications to be correlated with a communication graph, enabling further study of its properties.

Graph theory provides general formal methods for analysing specific physical systems, regardless of their complexity or nature. Such methods are particularly valuable for analysing and designing complex systems with heterogeneous elements. A graph visually represents the order and type of communications between elements of two sets, making it suitable for depicting structural diagrams.

The connection between a graph and a communication matrix is crucial for the practical application of topological methods in mathematically describing systems, as it translates structural features into numerical representations used in mathematical equations. Since a graph can be represented as a geometric figure, changes in the position of its vertices or the size and shape of its edges result in an equivalent graph, preserving its structure. This equivalence between a graph and its geometric representation underscores the suitability of graphs for depicting structural diagrams.

In constructing a structural diagram as a graph, the sources and receivers of information messages are represented as vertices, and the communication lines are depicted as edges. The resulting graph is termed a vertex graph. Representing a structural diagram as a graph allows abstraction from system-specific details, enabling a general analysis of their structures. For the QMS model, vertices represent processes, and edges represent communications between them. This concept is central to this study and aligns with the principles and requirements of the international standard (ISO 9001, 2015).

The creation of a structural diagram in the form of a graph is not an end in itself but serves to simplify subsequent research. This is supported by the existence of a systematic algebraic research methodology. Since studying a specific diagram's structure is equivalent to studying graph structures in general, structural theory can be viewed as a practical application of graph theory focused on analysing connections.

The analysis of communications in a graph primarily involves identifying and evaluating connections between its vertices. A communication path in a graph is a sequence of edges where the end of each edge coincides with the

beginning of the next. These edges, known as links, form the communication path. Single-link paths are termed direct, while multi-link paths are called transit. Figure 1 illustrates a directed graph where vertices 1 and 2 are connected by a direct communication path, and vertices 1 and 4 are connected by a transit communication path.

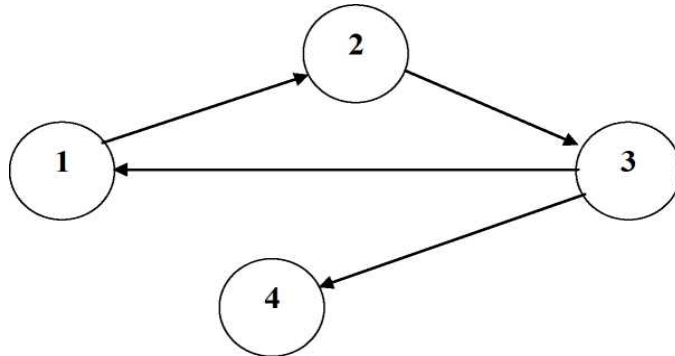


Figure 1: Oriented graph diagram

Source: Own processing, 2025

As follows from this definition, in the sequence of vertices of the graph through which communication passes, none of them occurs twice. If we abandon this requirement in the definition of communication, i.e., that all vertices must be different, we will obtain instead of communication a so-called series of edges leading from one vertex to another. Obviously, any communication is a series of edges; not every series of edges is a communication.

Referring to Figure 2, we see that in this graph the concept of communication between vertices 1-3 coincides with the concept of a series of edges. However, for vertex 1-4, these concepts do not coincide. Thus, from vertex 1 to vertex 4, there is one series of edges (1-2, 2-3, 3-4, 2-4) and two communications: (1-2, 2-3, 3-4), (1-2, 2-4).

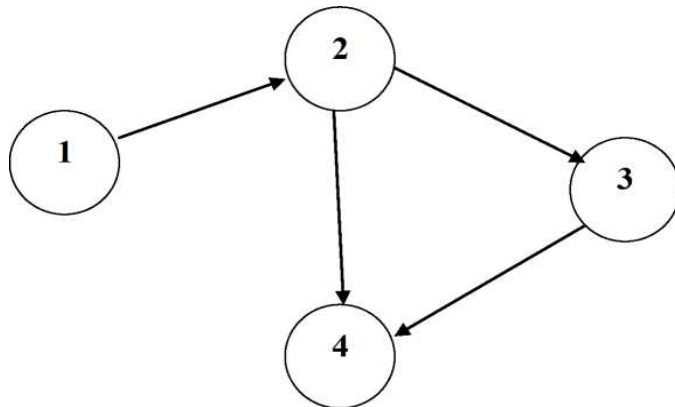


Figure 2: Oriented graph

Source: Own processing, 2025

The primary objective of structural analysis is to calculate the number of communications between two vertices of a graph, analyse their composition, and determine the maximum and minimum communication paths. All subsequent tasks stem from this core objective.

Searching for communications in a complex graph structure using general methods is challenging, prone to errors, and often yields results unsuitable for further analysis. The algebraic method significantly simplifies this process, minimises the likelihood of errors, and provides results in a format conducive to further research. The foundation of the algebraic method in graph analysis is the matrix of direct communications, which serves as an analytical representation of the graph, its mathematical model, and its algebraic form.

The process of constructing a matrix of direct communications involves the following steps:

- Determine the order of the matrix, which equals the number of vertices in the original graph.
- Number (or index) the vertices of the graph in an arbitrary order.
- Label the rows and columns of the matrix with these vertex numbers (indices).
- Assign a value of one (or, in a more general case, a non-zero natural number) to the element in the i -th row and j -th column if there is a direct communication from vertex i to vertex j ; otherwise, assign a value of zero.
- For example, referring to Figure 1, a graph can be represented algebraically as an adjacency matrix. An adjacency matrix (or communication matrix) is an $N \times N$ matrix, where N is the number of vertices in the graph. The matrix elements are set to 1 if a direct path exists from vertex i to vertex j , and 0 otherwise.

For the graph depicted in Figure 1, the communication matrix is structured accordingly:

$$A = \left| a_{ij} \right| = \begin{vmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{vmatrix} \quad (1)$$

The description of the structural diagram in the form of a graph (Figure 1) allows us to proceed directly to the analysis of structural features. Such an analysis, called structural-topological, involves the analysis of elements and communications that determine the structure and define the structural characteristics of the system. When studying the structure, it is particularly important to separate elements that are isolated, hanging, and dead-end vertices.

An isolated vertex is a vertex that is not connected to any other vertex. Such vertices should not occur in any system. The presence of an isolated vertex in a graph indicates errors made during the design or description of the structural diagram. A dead-end vertex is a vertex from which no edge of the graph emerges (no communication). If the sum of the elements of the matrix in a row is 0, then the vertex is a dead end. A hanging vertex is a vertex that has no edges entering it. If the sum of the elements of the matrix in a column is 0, then the vertex is hanging. It is not difficult to find isolated, hanging, and dead-end vertices using the matrix of direct communications. To do this, using the matrix of direct communications, find:

$$a_{ki} = \sum_{i=1}^n a_{ij}; \quad a_{kj} = \sum_{j=1}^m a_{ji}, \quad (2)$$

where a_{ki} – the sum of the elements of the i -th row of the matrix of direct communications. This is the number of edges emanating from the vertex k ; a_{kj} – the sum of the elements of the j -th column of the matrix of direct communications. This is the number of edges that belong to the vertex k ; n – number of rows in the matrix of direct communications m – number of columns in the matrix of direct communications.

If $a_{ki} = a_{kj} = 0$, to k – and the summit is isolated; if $a_{ki} = 0$, to k – and the vertex is a dead end; if $a_{kj} = 0$, than k – and the hanging peak.

Hanging and dead-end vertices correspond to the input and output elements of the system through which the process of interaction with the environment takes place. Since the QMS is an open system, such vertices may occur in its structural diagram.

Analysis of QMS Model Quality Indicators at the Design Stage

The representation of a QMS structural diagram as a graph or in any other form does not inherently provide insights into the system's qualitative indicators. Therefore, a methodology is required to identify and quantify specific structural parameters.

To ensure an objective evaluation of the QMS structural diagram at the design stage, it is advisable to employ qualimetric methods, which have proven effective in assessing complex technical and socio-economic systems.

Established approaches (Kupriyanov et al., 2023; Dyadyura et al., 2024) demonstrate the broad application of these methods in fields such as production process safety analysis (Cherniak et al., 2024; Trishch et al., 2024) enhancing measurement accuracy and consistency (Hrinenko et al., 2019; Trishch et al., 2019), and the industrial sector (Fedorovich et al., 2024; Hovorov et al., 2025). Particular emphasis should be placed on studies evaluating the operational quality of critical technical systems, such as energy infrastructure (Hovorov et al., 2024; Khomiak et al., 2024a, 2024b, 2025), which validate the integration of qualimetric principles in assessing QMS effectiveness.

While analysing the structural diagram's quality does not guarantee the system's overall quality, it enables an assessment by identifying "bottlenecks", highlighting them to developers, and uncovering hidden structural flaws. Given the limited initial data at the design stage, analysis is challenging. Typically, only a functional diagram with a general description of its operating principles and system-wide requirements is available.

In this context, the parameters used to evaluate the structural diagram's quality must be straightforward and rely solely on the data within the diagram itself. The following parameters are recommended for assessing a structural diagram represented as a graph: graph connectivity, element rank, and joint set.

Graph connectivity reveals structural flaws such as breaks (missing necessary communications), hanging or dead-end vertices, and other deficiencies in the functional diagram. The rank of an element indicates its importance within the model, determined by the number of connections it has with other elements. A higher rank signifies stronger connectivity and greater consequences in case of failure. The joint set identifies elements whose removal would dismantle the system, causing it to cease functioning as a cohesive whole.

These three parameters enable a quantitative assessment of the structural diagram's quality, addressing critical questions: Are there unintended breaks or dead ends in the diagram? How are elements distributed based on their structural significance? Which elements, if removed, would collapse the system? Collectively, these insights facilitate the objective allocation of efforts to enhance reliability during further system development and the identification and elimination of hidden structural flaws.

Determining the Completeness of Communications in a Structural Diagram

The first structural parameter that evaluates the quality of a diagram when represented by a graph is the connectivity of the graph. It is proposed to evaluate the connectivity of a graph by its structural connectivity, since this indicator is one of the most important structural characteristics and determines the minimum and permissible number of connections (communications) in the system. Obviously, for a system to be connected, there must be at least one connection between two elements. That is, the minimum permissible number of connections in the system must be:

$A_{\min} = N-1$, where N is the number of elements in the system. The total number of direct connections is defined as:

$$A_n = \frac{\sum_{i=1}^N \sum_{j=1}^N a_{ij}}{2}. \quad (3)$$

It is obvious that the system is connected and exists as a system if the condition is satisfied.

$A_n > A_{\min}$, that is:

$$\frac{\sum_{i=1}^N \sum_{j=1}^N a_{ij}}{2} \geq N - 1, \quad (4)$$

Hence, the structural connectivity coefficient:

$$R = \frac{A_n}{A_{\min}} - 1 = \frac{\sum_{i=1}^N \sum_{j=1}^N a_{ij}}{2(N-1)} - 1. \quad (5)$$

If $R > 0$, then the system has structural connectivity. If $R = 0$, then the system has minimal structural connectivity. If $R < 0$, then the system is not connected. This structural characteristic of the system can be used for indirect assessment of the system's efficiency, reliability, and survivability. Let us introduce the concept of relative connectivity of a system of arbitrary structure as an expression:

$$Q = \frac{A_n}{A_N} = \frac{\sum_{i=1}^N \sum_{j=1}^N a_{ij}}{N(N-1)} - 1, \quad 0 \leq Q \leq 1, \quad (6)$$

where: $A_N = \frac{N(N-1)}{2}$. – parameter of absolute connectivity for a fully connected undirected graph with N vertices. That is, A_N is equal to the maximum number of edges in the graph for a given number of N vertices. In other words, the relative connectivity index of a system is the ratio of the number of existing connections to the number of possible connections (Figure 3).

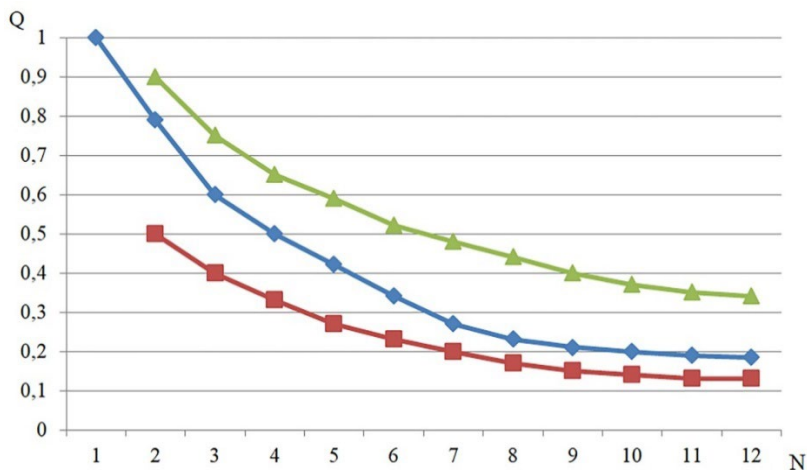


Figure 3: Dependence of the connectivity of structure Q on the number of vertices N
Source: Own processing, 2025

The next characteristic of a structural diagram is the rank of an element. This characteristic allows elements to be ranked according to their importance. It is believed that the more important an element is, the more connections it has with other elements. In general, to determine the rank of an element, it is necessary to use a matrix of direct communications.

$$r_i = \frac{\sum_{j=1}^N a_{ij}}{\sum_{i=1}^N \sum_{j=1}^N a_{ij}} \quad (7)$$

Analysing formula (7), it can be seen that the rank of an element is nothing more than the ratio of the connections of one element to the total number of connections of the entire system.

The next characteristic of a structural diagram is survivability. Survivability is understood as the ability of a system to ensure the transmission of information between elements under the influence of interfering factors. The survivability index is the average proportion of communications that continue to function in the event of the loss of other communications:

$$W_g = 1 - \frac{gg!(A-g)!}{AA!} \quad 0 \leq W_g \leq 1, \quad (8)$$

where g – number of lost communications, A – total number of communications.

Figure 4 shows the dependence of system survivability on the condition that the number of elements in the system $N=4$, and the number of connections $a= 3; 4; 5; 6$.

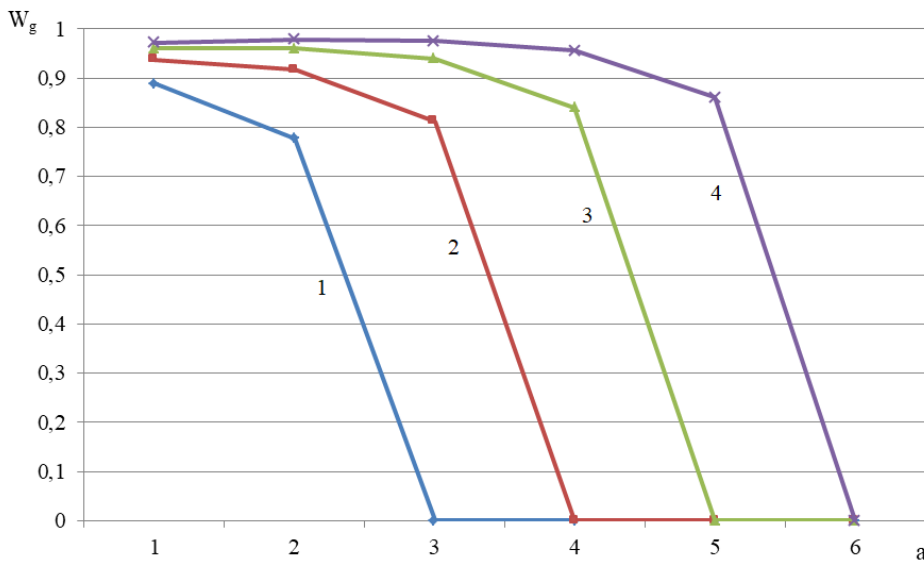


Figure 4: Dependence of system survivability on the number of its elements

Source: Own processing, 2025

Thus, representing QMS in the form of a structural diagram using graphs allows, with the help of quantitative indicators, the identification of potential problems even before the start of realisation – in particular, to determine excessive complexity or insufficient interaction between elements, to localise areas of risk of communication loss, and to assess the impact of each element on the integrity of the entire system. Thus, structural analysis not only reduces the likelihood of strategic errors, but also contributes to the creation of a more resilient, flexible, and effective quality

management system that is capable of self-learning, rapid response to environmental changes, and stable functioning in the face of external challenges.

This article proposes the application of systems theory and a systems approach to the management of organisations at various levels. When considering an enterprise management system as a holistic system, it is reasonable to assume that its functioning is governed by certain patterns. Traditionally, methods of mathematical statistics or mathematical physics are used to describe such processes; however, such systems are characterised by limited statistical data and their non-stationary, which significantly complicates the processes of assessment, forecasting and management.

In this regard, the article proposes the use of the mathematical apparatus of systems analysis, which allows for the effective study and management of complex systems under conditions of uncertainty and limited information. This approach is universal and can be applied to a wide range of management systems.

The proposed methodology is based on the fundamental principles of systems analysis, which provides grounds for considering it as a basic foundation for the development of applied management techniques at the level of a specific enterprise. It serves simultaneously as a mathematical framework and as a methodological tool.

The application of this methodology opens up opportunities for creating tailored management solutions that take into account the specific characteristics of the enterprise, in particular its scale, type of production, country of operation, political environment and other factors. Consequently, the presented study has significant potential for further development and practical implementation.

4 Discussion and Conclusion

The findings of this research confirm and extend the conclusions of earlier studies on the role of communication in the successful implementation of ISO 9001:2015 in socio-economic systems. In agreement with Özkan (2021), our study shows that well-structured internal and external communication supports transparency, strengthens staff engagement, and facilitates the achievement of quality objectives. Similar to various authors (Bravi et al. 2019; Limón-Romero et al., 2024), we found that communication functions not only as a technical process but also as a mechanism of organisational integration, aligning roles, responsibilities, and performance indicators across departments.

A significant contribution of this study lies in the application of graph-based modelling, which provides a quantitative method for assessing communication structures. While many previous works (Bouchetara et al., 2022; Arslan et al., 2023) evaluated communication effectiveness through surveys, interviews, or maturity models, these approaches often lack the ability to detect hidden structural flaws. Our results demonstrate that graph theory allows identification of isolated, dead-end, or hanging vertices in the QMS structure – elements that, if left unaddressed, could lead to disruptions in quality processes.

Interestingly, some researchers (Renosori et al., 2023; Tarigan & Rajagukguk, 2023) emphasised that the main challenges in ISO 9001:2015 implementation arise from resource constraints, insufficient training, or resistance to change. Our findings suggest a different yet complementary perspective: these factors, while critical, often manifest their negative impact through weakened communication networks. Limited resources may delay information exchange, reduce redundancy in communication channels, or overburden critical nodes, increasing the system's vulnerability.

Another difference lies in the stage of application. Much of the literature focuses on post-implementation evaluation and corrective measures, whereas our methodology proves effective at the design stage, when the system is only being conceptualised and data is limited. This proactive approach aligns with the recommendations of systemic risk assessment studies (Kupriyanov et al., 2023; Dyadyura et al., 2024), highlighting the importance of early-stage diagnostics to prevent costly rework.

Moreover, while earlier works (Ruão et al., 2022; Hutchinson & Ahmad, 2024) explored the influence of digital communication tools on organisational efficiency, they did not integrate these findings into a structural analysis of the

entire QMS. Our method can incorporate digital channels as specific vertices in the graph model, allowing the assessment of their role and criticality within the overall communication framework.

Overall, the combination of systems analysis and graph theory not only validates the theoretical insights of previous research but also offers a robust, data-driven tool for practical application. This enables managers and quality specialists to make evidence-based decisions on optimising communication flows, enhancing resilience, and ensuring ISO 9001:2015 compliance in dynamic socio-economic environments.

An effective communication system is a pivotal factor in the successful operation of a QMS within complex socio-economic systems. The implementation of ISO 9001:2015 relies on well-established information flows amongst all organisational structural elements. Communication within the QMS not only facilitates action coordination, mitigates organisational risks, and enhances the quality of management decisions but also serves a system-forming function, ensuring the stability and integrity of the entire management structure. In socio-economic systems characterised by high dynamism and multi-level, multi-component connections, systematic analysis enables comprehensive coverage of all communication environment aspects, including content, timing, recipients, channels, and responsible individuals. This approach identifies inefficient or overloaded information exchange areas and ensures the QMS's adaptability to a constantly evolving environment, a critical prerequisite for enhancing an organisation's competitiveness in the context of globalisation.

Representing the QMS as a graph provides an effective analytical model for researching, designing, and optimising communications. Utilising graph theory for QMS modelling transitions from intuitive descriptions to formalised, quantitative assessments of the system's structure. This method enables the identification of key system nodes, detection of isolated, dead-end, or hanging vertices, and evaluation of the quality of information links between elements. Graph parameters – such as connectivity, element rank, joint sets, and survivability index – facilitate assessing the QMS's structural integrity, resilience to information failures, presence of critical areas, and potential for recovery post-functional failures. This graph model supports comparative analysis of various organisational structure or communication model options before implementation, significantly reducing error risks in later stages and enabling the optimisation of management resources prior to the practical adoption of the ISO 9001 standard.

These parameters allow for a quantitative evaluation of the structural diagram's quality, enabling a more precise and objective allocation of efforts to ensure reliability during further system development and the identification and elimination of hidden structural flaws.

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